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AFFTC

ENVIRONMENTAL CONTROL SUBSYSTEMS

FLIGHT TEST HANDBOOK

December 1982

AIR FORCE FLIGHT TEST CENTER
EDWARDS AIR FORCE BASE, CALIFORNIA
AIR FORCE SYSTEMS COMMAND
UNITED STATES AIR FORCE

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This Handbook provides AFFTC engineers with guidelines for the testing of environmental control subsystems. Future technological advances, characteristics or individual aircraft or programs may necessitate other methods being used in some cases. A background is provided on environmental control subsystems and the requirements to which they are designed. Details are provided of individual tests, test support requirements and evaluation criteria and suggestions made for presentation of results.

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PREFACE

This handbook presents the methods used in testing and evaluating aircraft environmental control subsystems at the Air Force Flight Test Center (AFFTC), Edwards AFB, California. The work was done under the authority of the Study Plan for Development of a Handbook for Aircraft Environmental Control Subsystem Testing.

The format of this handbook is chosen to make it easily used by project engineers of the Subsystems Branch, Airframe Systems Division of Flight Test Engineering, AFFTC. It is designed to introduce a newly assigned flight test engineer to the subject and provide a working reference for planning and conduct of environmental control subsystem flight tests and analysis, evaluation and reporting of results.

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INTRODUCTION

The purpose of this Handbook is to provide the AFFTC flight test engineer responsible for evaluation of an airplane environmental control system (ECS) with the background, philosophy and procedures for planning, conduct, data analysis and evaluation of ECS tests. It is advisory in nature and neither supersedes Air Force requirements nor relieves the Flight Test Engineer of the exercise of judgement in its application.

The subjects addressed include the following:

1. The objective of the AFFTC evaluation and its relationship to design requirements and to the needs of the operational user.

2. ECS elements and basic functions.

3. A review and analysis of requirements.

4. Planning of flight tests.

5. Data analysis and system evaluation.

[redacted]

OBJECTIVES AND ENVIRONMENT OF ECS TESTS

The charter of the AFFTC is the development, test and evaluation of new and modified weapon systems. In this role the Center is a bridge between the design engineer and the operational user. Center evaluations of aircraft require not only engineering expertise to conduct a technical evaluation but also a keen and perceptive evaluation of the needs of the operator and of the environment in which the aircraft is to fulfill its mission. As an illustration of operator needs one may consider the tactical pilot who may have to operate in an environment ranging from difficult and distracting to actively hostile. The ECS should be designed to minimize pilot distraction and work load. Similarly, field servicing should be fast, simple and as error proof under stress as is reasonably feasible.

Considerable attention will necessarily be given to testing against specific requirements but the flight test engineer should seek comment from flight crews with operational experience and continuously encourage ground crews to evaluate the aircraft as an operational system. This Handbook attempts to emphasize this approach but in the final analysis it cannot be fully defined in print but must be ensured by the attitude and objectives of the test team.

POSITION OF AFFTC IN THE DEVELOPMENT AND EVALUATION PROCESS

The contractor responds to the specific, program peculiar requirements of his contract and to general system requirements with an "end item specification" for the ECS of his aircraft. The contractor is required to demonstrate compliance with specifications by flight test of an aircraft representative of the production version. The primary function of the AFFTC is to oversee and cooperate in these tests, perform independent analyses of the data and, if necessary, conduct additional tests.

AGENCIES INVOLVED

Tests of the ECS are conducted at the AFFTC, usually by a Combined Test Force, involving a number of Air Force agencies as well as the contractor. Table 1 (page 13) shows the interest and responsibility of each of the major agencies involved. It is important to appreciate the interest and expertise of the agencies involved in order to cooperate effectively. For example,

a. The contractor develops the system and demonstrates to the System Program Office that it meets specifications.

b. The System Program Office reviews and analyzes the data to check compliance.

Table 1

INTEREST AND RESPONSIBILITIES OF MAJOR AGENCIES INVOLVED

IN DT&E FLIGHT TEST OF ECS

TYPE TEST AGENCY	DEVELOPMENT	DEMONSTRATE TO SPECIFICATIONS	RELIABILITY & MAINTAINABILITY	OPERATIONA EFFECTIVENE
Contractor	Yes	Yes	Assist	No
ASD/SPO	Direct	Check Compliance	Check	No
AFFTC	Liaison	Oversight & Independent Analysis	Primary Responsibilities	Yes
AFTEC	No	No	Yes	Primary Responsibili
User Command	No	No	Advance Data Advice	Advance Dat Advice
Air Training Command	No	No	Advance Data	Advance Dat
Logistics Command	No	No	Advance Data	Advance Dat Advice

NOTES:

ASD = Aeronautical Systems Division

SPO = System Program Office

AFTEC = Air Force Test and Evaluation Center

*On some in-service aircraft Air Force Logistics Command as Program Manager will be the test requester rather than a System Program Office of Aeronautical Systems Division.

c. The AFFTC independently analyzes data, performs additional tests as necessary, provides independent evaluation as required, and reports to the System Program Office.

The AFFTC flight test engineer conducts tests or participates in tests conducted, as necessary, to ensure that AFFTC responsibilities are met. As the flight program and development of the test aircraft progresses the relative roles and responsibilities of the member of the test team will change. Initially, emphasis is on development testing. At this time the contractor has a lead role while the AFFTC engineer participates and conducts his own analyses and evaluations. Later, emphasis shifts to test and evaluation, with increased participation by AFTEC and using commands. The AFFTC engineer then assumes a lead role. Even though much of the work may be performed by the contractors team he must initiate and conduct tests, as necessary, and oversee analysis and evaluation of results.

MULTI-PURPOSE FLIGHT TESTS

Many ECS tests will be performed during other tests or during flights which also involve other tests. Hence, the engineer responsible for the ECS test must:

a. See that his tests are properly performed.

b. Encourage the flight and ground crews to report any incidents pertinent to the ECS.

With regard to the proper performance of tests, ECS tests are often performed piggyback on other tests or as alternate missions when the primary mission cannot be performed. The ECS test engineer must see that his tests are properly briefed and that the necessary instrumentation is functional and is used.

Also, the subsystem engineer must interface in some areas of test with other AFFTC organizations such as Human Factors, Reliability and Maintainability or Technical Order Verification and Validation. Such interfaces are identified in the section on planning of flight tests. For this purpose he should identify contacts within these organizations to facilitate good liaison. For example contamination measurements and evaluations of the functioning of pressure suits and oxygen systems may actually be performed by Human Factors engineers. All-weather tests are usually performed on the total weapon system under the direction of an all-weather test engineer. The ECS test engineer works closely with the all-weather test engineer to develop the test program, plans for the retrieval of his data, conducts the analyses and writes the subsystem report.

ECS FUNCTIONS AND ELEMENTS

The ECS performs the following functions when they are required on a particular type of aircraft:

(a) Distribution of engine compressor bleed air between the engine(s) and the components and subsystems that require bleed air.

(b) Air conditioning, pressurization, cooling, heating, ventilation, contamination control and moisture control of occupied compartments, equipment compartments and electronic equipment.

(c) Anti-icing or de-icing of flight surfaces, radomes, antennas and ram air scoops.

(d) Removal of rain, snow, ice, frost, fog, dust and insects from transparent surfaces and sensor windows.

(e) Pressurization and temperature control of air for anti-g suits, pressure suits and ventilation suits. Pressurization of inflatable pressure seals, subsystem reservoirs and miscellaneous equipment.

(f) Purging of gun gas and of vapor and fuel from air refueling manifolds.

(g) Oxygen supply.

This section presents an overview of each of these functions and the design approaches to them which are commonly used. These approaches vary widely. For example, cabin heating on Air Force aircraft normally uses heat from main propulsion compressor bleed air (from turbine engines) or an Auxilary Power Unit (APU), but it can be obtained from engine or APU exhaust heat exchangers or from electric or combustion heaters. The air used for cooling also comes from compressor air bleed. This air may be cooled by air or vapor cycle refrigeration, ram air, expendable coolants, heat storage materials, thermoelectric refrigeration or similar techniques. In order to preserve a reasonable degree of readability, the descriptions and discussions in this section will primarily address the approaches commonly used in Air Force aircraft, including:

(a) Use of engine/APU bleed air for heating.

(b) Air cycle or vapor cycle refrigeration.

Because of the variety in design approaches and in the details of implementation it is imperative that the ECS flight test engineer become very familiar with the details of the system under test by studying the end item specifications of the aircraft manufacturer and relevant Technical Orders. He should read the manufacturers design analysis and failure modes and effects analysis for the system and also those parts of the SAE Aerospace Applied Thermodynamics Manual (Ref 1) which apply. He should avail himself of the special contractor training, both design and maintenance, which is usually given to key personnel on a new system. A useful self taught ECS mechanics course is available through the Education Office (Ref 2).

Simulation techniques are available for the air conditioning/pressurization elements of the ECS. In particular the 'EASY' program, available and operating at AFFTC, is specificially designed for ECS modeling. Use of such simulation can be most valuable in:

(a) Ensuring that the engineer is indeed familar with the inner workings of the specific system with which he is concerned

(b) Anticipating potential problem areas and

(c) Understanding problems which may arise.

ENGINE COMPRESSOR BLEED AIR SYSTEM

On turbine engined aircraft, the engine compressor is a very convenient source of hot, high pressure air, which is used as the primary source of pressurized air to supply such elements as occupied compartments, fuel tanks, inflatable pressure seals, anti-g suits and so on. The compressor bleed air system includes all the ducting, conditioning and controls between the primary and alternate sources (bleed ports or manifolds on the engines, auxiliary power units, ground support equipment and so on) and the using element. For example, it does not include the ports or manifold on the engine or the fuel tank pressurisation controls but does include everything in between. The bleed air system is used to provide each element with air at the rates and pressure which that element needs.

The bleed air is very hot (approximitely 600-900 degrees F) when it leaves the engine. The bleed air system therefore includes a "preconditioning" heat exchanger to reduce bleed air temperature so that the hot air will not ignite fuel or hydraulic fluid. This heat exchanger is usually a ram air type which dumps the heat to outside air. On some installations the cooling air for the heat exchange is bled from the engine fan. Additional conditioning will, in general, be required of the air delivered to each subsystem

served. For example, the air supplied to an anti-g suit must be controlled between 55 and 130 degrees F, that to a pressure suit between 55 and 90 degrees F.

Inflatable seals, unlike pressurized fuel tanks, are defined as part of the ECS. These seal doors canopies and so on to enable pressurization.

Figure 1 (page 18) shows an example of an inflatable seal for the F-15 canopy. Locking the canopy admits air to the seal at a regulated pressure of 20 ± 1 PSIG. Unlocking the canopy shuts off the pressurized air and vents (deflates) the seal.

Gun gas purge systems are used to purge accumulated gun gas during and after firing. The main components are a purge shutoff valve and ejector, gun gas exhaust tube, check valve, manifold and time delay relay. The purging airflow to the gun compartment is controlled by a solenoid-operated shutoff valve that is activated by the gun trigger switch. The valve will be held open by a time delay relay for approximately 30 seconds after firing has ceased. Purge air and gun gases are directed through a ejector to the purge exhaust port.

In-flight refuel purge systems are used to clear the air refueling manifold of residual fumes and/or fuel following air refueling operations. The main components of the refuel purge system are a purge solenoid-operated valve, a purge drain solenoid-operated valve, and two uni-directional check valves. Preconditioned bleed air is used for purging.

AIR CONDITIONING AND PRESSURIZATION

Under this heading we will include pressurization, cooling, heating, ventilation and moisture control of occupied compartments and also equipment bays. Specific approaches to cooling of equipment, which are themselves quite varied, will be illustrated later in this section.

Major challenges involved in the above functions include:

(a) Cooling on the ground after prolonged heat soak

(b) Moisture control when the moisture content of the outside air is high

(c) Air distribution at desired temperature and flow conditions under widely varying conditions of altitude (pressure), temperature, aerodynamic heating and solar radiation

(d) Cooling of equipment such as radar transmitters which produce high heat loads.

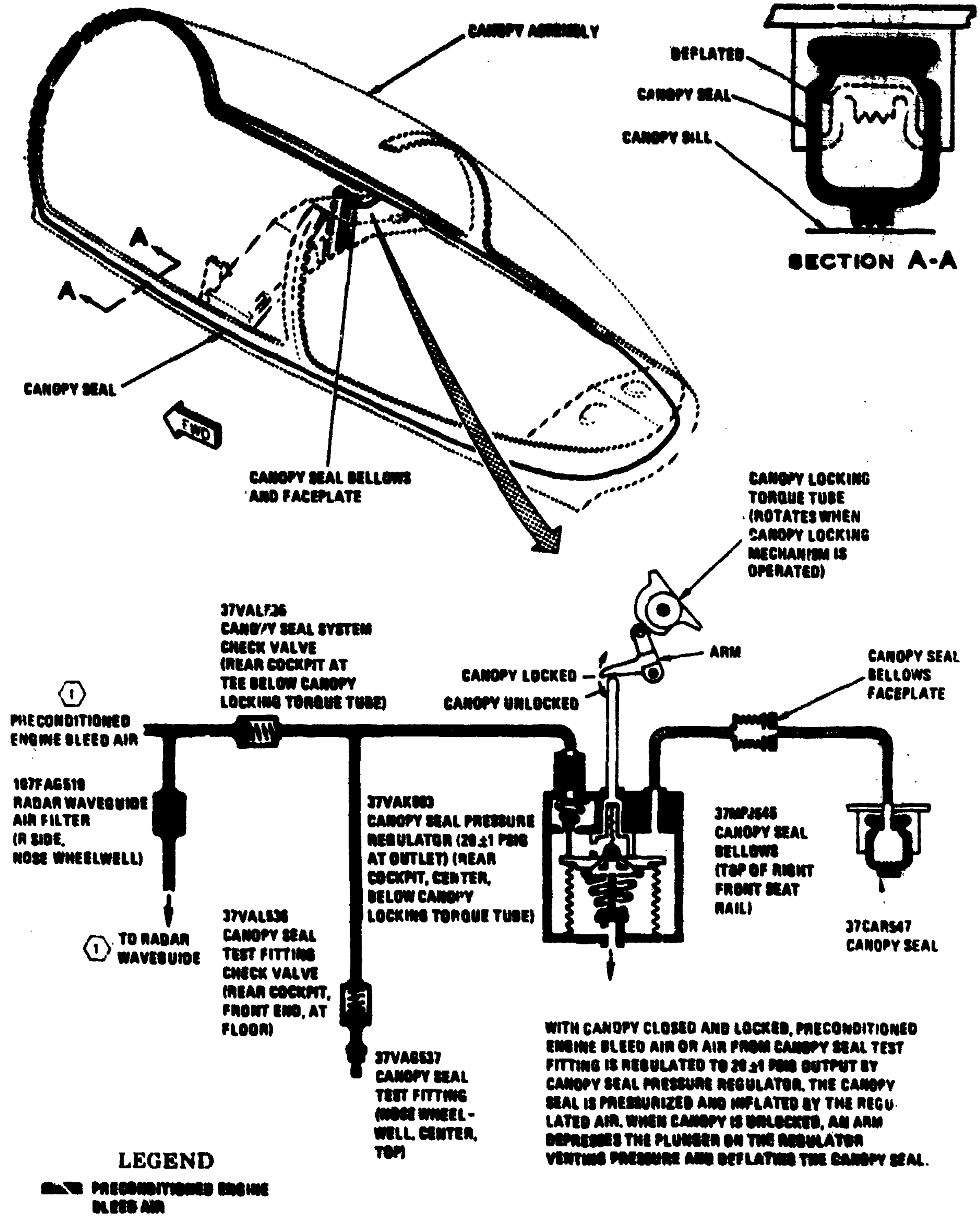


Figure 1 F-15 Canopy Inflatable Seal System

Heating, cooling and pressurization are integrated functions. For example, pressurization of occupied compartments is effected by supplying conditioned air in sufficient quantity to provide proper ventilation, overcome leaks and still provide enough air for desired rates of increase of cabin pressure when the aircraft is descending at reduced power. On Air Force aircraft pressurized air is usually taken from the engine compressor or an APU and is already very hot. Part of it is refrigerated and the temperature into the compartment is controlled by mixing of the refrigerated air with unrefrigerated air.

Pressurization:

There are three pressure control modes involved; isobaric, differential pressure control and rate of change control. In the first mode a selected pressure altitude is maintained in the cabin. On transport aircraft this can be selected by the crew to be any value between -1000 ft and +10,000 ft. The second mode prevents the differential pressure from exceeding the structural limit of the compartment, and overrides the isobaric control as necessary. The third mode limits the rate of change of pressure for purposes of crew comfort. It overrides the isobaric control but is overriden by the differential pressure control. An additional, independent safety valve system is required to prevent structurally dangerous positive or negative differential pressures.

Provisions are required for normal and emergency pressure release for occupied compartments. The normal pressure release can dump cabin pressure without shutting off the pressurized air source. The emergency pressure release dumps the cabin pressure rapidly and shuts off the source of pressurized air. An emergency ram air ventilation system is required for use with the emergency dump.

Ventilation is usually "open cycle", with used air being dumped overboard. Sometimes the used air is first routed through equipment compartments to condition them, or through such systems as the galley or toilet ventilation systems before being dumped. In a few cases "closed cycle" air supply is used, in which the air is re-circulated with make-up air added to overcome leaks and so on.

Temperature Control:

Temperature control involves both heating and cooling of occupied areas and equipment. One of the major sources of ECS complexity is cooling, which requires removal of heat from the occupied area or equipment and dumping it into some "sink" such as the outside air. Since the "sink" will often be at a higher temperature than the desired cabin temperature (as with ram air

on a hot day or at high Mach number) a heat pump system is required. Most Air Force aircraft use "air cycle" air conditioning, in which air is the working fluid in the heat pump. However, large high speed aircraft may use vapor cycle systems, similar in principle to the domestic refrigerator or freezer. Such systems can handle high loads and a large temperature difference between the heat source and the heat sink.

An excellent discussion of refrigeration system design is given in Part 3B of Reference 1 (SAE Aerospace Applied Thermodynamics Manual). The flight test engineer should consult this concerning the particular type of system used in the aircraft being evaluated. The refrigeration system may be air cycle (air as the working fluid) or vapor cycle. Schematics of some of the more representative types will now be discussed, followed by examples of actual systems (F-15A and E-3A).

Basic Closed Air Cycle System.

Figure 2 (page 21) shows a schematic of a basic closed air cycle system. The air passed through the cabin or equipment compartment is also the working fluid of the refrigeration system. Compression of air raises its temperature, which makes the heat exchanger more effective and also enables expansion through the turbine, to provide the additional cooling needed (usually to 25-30 degrees F.).

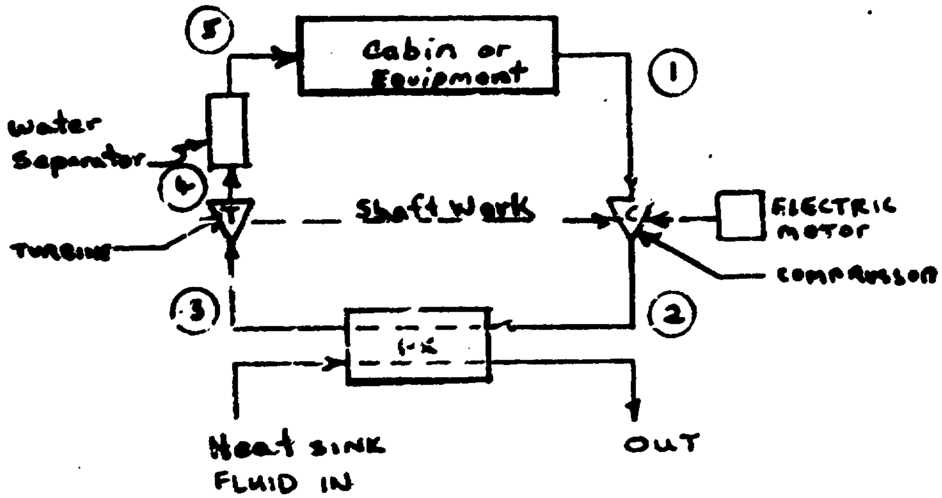
More air is added as necessary to overcome leakage and maintain adequate levels of oxygen. This cycle is theoretically more efficient than the boot strap or regenerative cycles for Mach numbers above about 2.5. It has a low operating pressure and is easy to control, but is rarely used in Air Force applications.

Open Air Cycle Systems.

Open air cycle systems are of three general types which will be discussed in order of their complexity.

Basic Open Air Cycle System

Figure 3 (page 22) shows an illustrative schematic of this type of system. The pressurized (hot) air from the main engine compressor bleed is first cooled by a "primary" heat exchanger which dumps heat to outside air. The cooling air flow may be augmented on the ground by ejectors or by a fan. The pressurized air is then further cooled by expansion through a turbine before being passed through the cabin or equipment compartment and discharged overboard through a pressure regulator. Work from the turbine may be used by a fan to draw cooling air over the heat exchanger as in the case shown. This simple type is unlikely to be encountered on Air Force aircraft.



(1)→(2) Exhaust air from cabin or equipment is compressed, raising its temperature, Part of compressor work from electric motor.

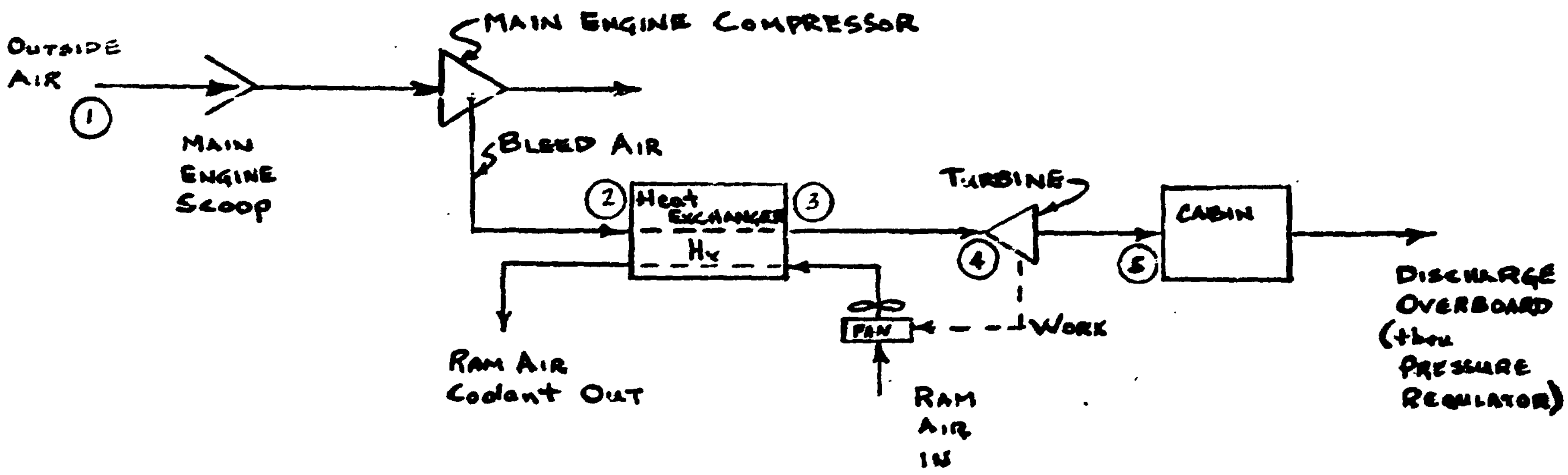
(2)→(3) Air cooled in heat exchanger.

(3)→(4) Air further cooled by expansion through turbine. Turbine supplies part of compressor work.

(4)→(5) Condensed water removed before air is returned to cabin or equipment.

- For Mach numbers > 2 the closed cycle is more efficient than the open cycle
- Low operating pressure ratio and easier to control.
- External power is required to drive compressor.

Figure 2 Basic Closed Air Cycle System



1→2 Air is bled from engine compressor or supplied by engine-driven compressor

2→3 Air is pre-cooled in heat exchangers

4→5 Air is expanded in turbine, resulting in cooling of air flow. Energy from the turbine is absorbed by the ram air fan.

Bleed air requirement is relatively high

High pressure ratios are required for adequate cooling

Figure 3 Basic Open Cycle System

Bootstrap Type System

Figure 4 (page 24) shows a schematic of bootstrap (open cycle) systems. After the air is passed through the pre-conditioning heat exchanger it is compressed (raising its temperature), cooled by passage through a second ram air heat exchanger, then further cooled by expansion through a turbine which drives the compressor. This type of system is widely used on medium performance (subsonic) Air Force aircraft such as the E-3A. Relative to the basic system, it lowers bleed air requirements. Component modeling and pressurization control are relatively easy. For altitude operation it can provide rated cooling over a wide range of flight conditions. Some form of assistance (fans, ejector) is necessary for ground cooling when no ram air pressure is available.

At Mach numbers above about 1.3 cooling by ram air in the secondary heat exchanger becomes inadequate, requiring either a regenerative system or use of fuel or an expendable fluid as a heat sink.

Regenerative Air Cycle System

This type system is often used on aircraft with a high Mach number capability, such as the F-15 and F-16, for which the temperature of the ram air may be quite high. It is similar to the bootstrap type system except that some of the cooled air leaving the turbine is used to pre-cool the air entering the turbine and is then dumped overboard. Alternatively, water from the water separator may be used for this purpose (F-16).

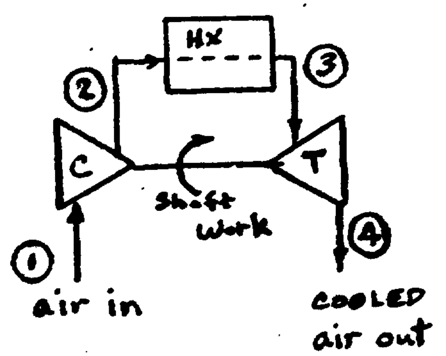
Basic Vapor Cycle System.

Figure 5 (page 25) shows a schematic for a basic vapor cycle system. The refrigeration system is closed cycle. Heat is absorbed from the heat exchanger by vaporizing the working fluid, which is then compressed and condensed in the heat sink. The refrigerated fluid flow (cabin air, etc) may be open cycle or closed cycle. This type of system is efficient, gives high capacity and permits placing cooling units in remote locations. However, it is heavier and less compact than air cycle systems and requires a separate source for cabin pressurization. Such a system is used on the B1.

Combination Vapor/Air Cycle System.

Figure 6 (page 26) shows an illustrative schematic of a vapor/air cycle system which combines some of the advantages of both systems, using a closed cycle refrigerating system and an open cycle cabin air supply system.

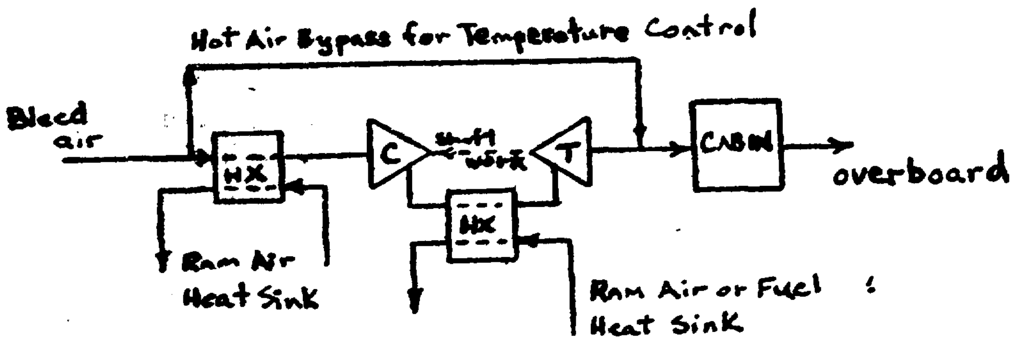
BASIC



(1)→(2) Air from source is compressed

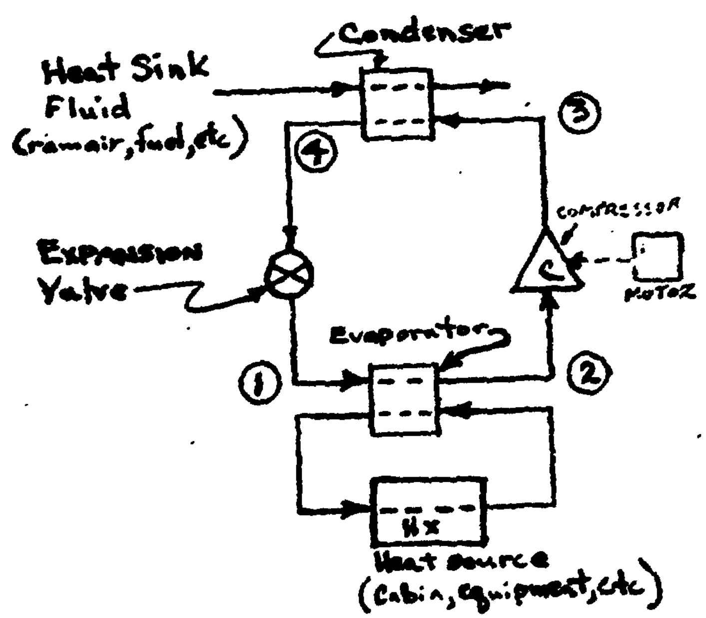
(2)→(3) Heat of compression removed in heat exchanger

(3)→(4) Air expanded thru turbine to cool, work abosrbed by compressor



- Normally used on aircraft where available air pressure levels are limited (Low pressures result in poor cooling w/air cycle systems)
- Lowers bleed air pressure requirements

TYPICAL



1 → 2 Absorption of heat evaporates liquid refrigerant into vapor

2 → 3 Vapor compressed

3 → 4 Loss of heat to heat sink condenses refrigerant vapor

4 – 1 Pressure reduced in expansion valve – temperature reduced

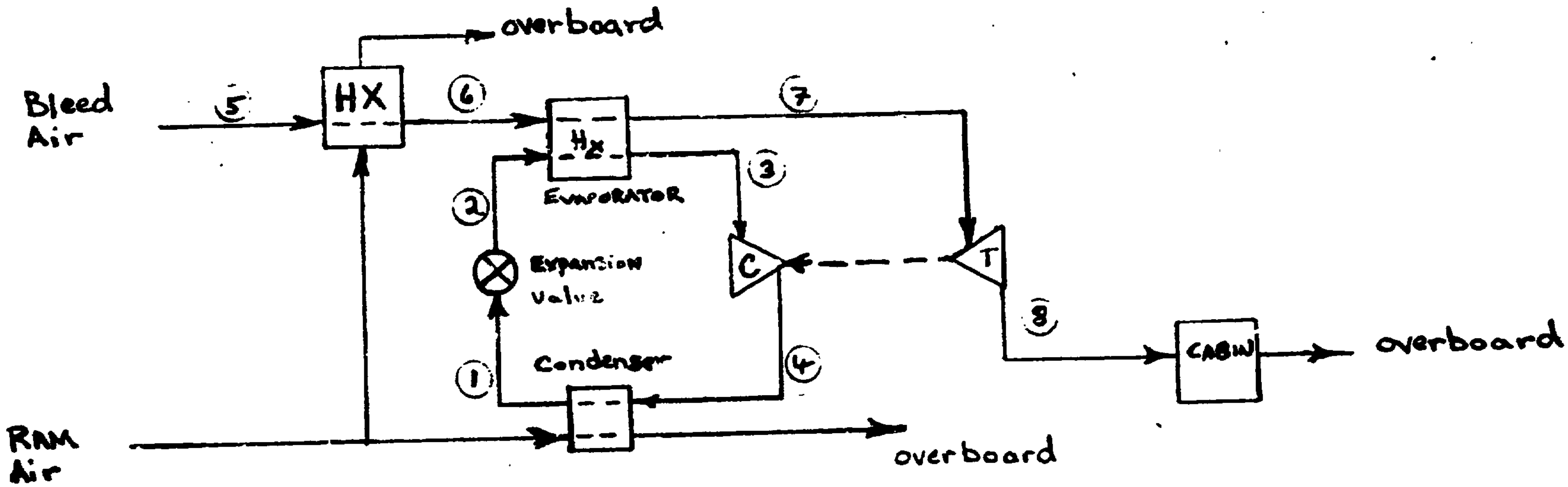
ADVANTAGES OF VAPOR CYCLE SYSTEMS

- High Coefficinet of Performance
- Permit *Centralized* unit with cooling to *various locations*
- Large capacity ground cooling & pulldown capabilities
- Smaller fresh air requirements

DISADVANTAGES

- Higher weight
- *Requires separate source for cabin pressurization*

Figure 5 Basic Vapor Cycle System



(1)→(2) Refrigerant cooled by expansion through valve

(2)→(3) Absorption of heat from bleed air evaporates refrigerant.

(3)→(4) Refrigerant vapor compressed, raising temperature

(4)→(1) Hot vapor cooled and condensed

(5)→(6) Bleed air pre-cooled

(6)→(7) Bleed air cooled by evaporating refrigerant

(7)→(8) Bleed air further cooled by expansion through turbine. Turbine compressor

Evaporator provides additional cooling during periods of reduced ram air

Turbine can provide power to drive compressor

Move versatile than single type system

Figure 6 Combination Vapor/Air Cycle System

Water Separators:

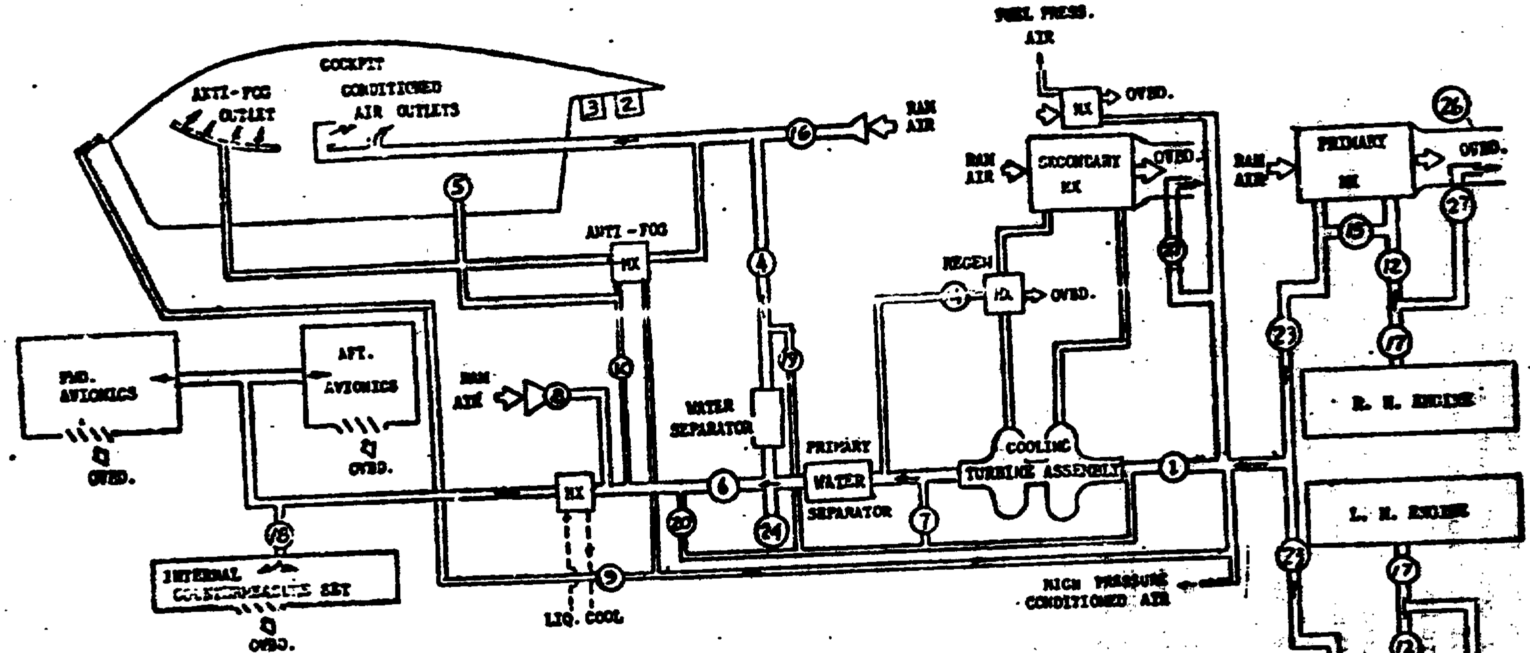
Moisture removal is a major challenge in a hot, humid environment not only for crew comfort but also to protect avionics and to control problems of corrosion and fungus growth resulting from condensation over equipment.

With air cycle air conditioning water separation is usually mechanical. The air leaving the air cycle turbine is very cold and much of the moisture will have condensed into water droplets. It is desirable to allow enough distance for these droplets to agglomerate to 1-2mm in size before entering the separator. A simple separator consists of a coalescer unit to catch the droplets, collector tubes and plates, and an internal relief valve to bypass the coalescer if it is blocked by ice. The coalescer unit has a filtration element which changes the droplets into larger drops, which are then blown on to collector tubes or plates. A centrifugal device (a turbine rotor or swivel turbine) can also be used provided that the droplets are large enough for effective separation. With vapor cycle refrigeration the water will usually condense on the heat transfer surfaces of the evaporator unit and can be collected in a downstream trap.

Examples of Actual Systems:

Figure 7 (page 28) shows the schematic of the F-15 system, which is of the regenerative type (reference 3). The following discussion of the operation of air cycle systems relates primarily to this example, but some common variations from it are also discussed.

Bleed air leaves the engines through pressure regulator/shut-off valves (item 17 in the diagram) and goes to the primary, preconditioning heat exchangers where it is cooled by ram air, the resulting temperature being controlled by a bypass temperature control (item 15). Some bleed air can be diverted (27) to ejectors to induce flow through the heat exchangers on the ground. Air for air conditioning then goes through the flow control (1) to the compressor component of the compressor/turbine assembly. This compressed air is then ducted to the secondary heat exchanger where the heat of compression is transferred to ram air. The airflow is next routed through a regenerative heat exchanger to the turbine/compressor where it is expanded through the turbine component. During the expansion process, the air may be reduced to subfreezing temperatures, dependent upon ambient air temperature and humidity conditions. Some of this cooled air is looped back to the regenerative heat exchanger, (14), to pre-cool the air entering the turbine, before being dumped overboard. (It is this regenerative feature, needed at high Mach numbers, which distinguishes these systems from ordinary bootstrap systems.) All conditioned air then goes to the primary water separator, downstream of which cabin conditioning air is channeled through a second water separator,



1. FLOW CONTROL AND SHUTOFF
2. CABIN PRESSURE REGULATOR
3. CABIN SAFETY
4. CABIN FLOW CONTROL
5. ANTI-G
6. AVIONICS FLOW CONTROL
7. WATER SEPARATOR ANTI-ICE CON
8. AVIONICS EMER. RAM AIR
9. WINDSHIELD ANTI-ICING
10. ANTI-FOG TEMPERATURE CONTROL
11. DELETED
12. BLEED AIR PRESSURE REGULATOR & SHUTOFF
13. DELETED
14. REGENERATIVE HX TEMPERATURE CONTROL
15. PRIMARY HX TEMPERATURE CONTROL
16. CABIN EMER. RAM AIR
17. PRIMARY PRESSURE REGULATOR/SHUTOFF
18. INTERNAL COUNTERMEASURES SHUTOFF
19. CABIN TEMPERATURE CONTROL
20. AVIONICS TEMPERATURE CONTROL
21. DELETED
22. DELETED
23. PRECONDITIONED BLEED AIR CHECK VALVE
24. GROUND COOLING CONNECTION
25. DELETED
26. PRIMARY HX EJECTOR
27. EJECTOR SHUTOFF VALVE

Figure 7 F-15 Environmental Control Subsystem

mixed with non-refrigerated air to produce the desired temperature and ducted to the cabin.

In the E-3A (reference 4), the occupied area is divided into four zones. A bootstrap air cycle system cools the conditioned bleed air sufficiently to cool the most demanding zone. Unrefrigerated bleed air is then mixed with the refrigerated air going to the other zones to "trim" the air temperature in them as required.

AVIONICS/EQUIPMENT COOLING AND PRESSURIZATION

Equipment cooling requirements cover a wide range, up to very high heat dissipation requirements for radar transmitters. Correspondingly, a wide range of cooling techniques is used, which includes:

(a) Free convection air cooling (conditioned air supplied to the equipment compartment, sometimes from outflow from occupied compartments).

(b) Internally forced air cooling (conditioned air supplied to the unit).

(c) Cold plate forced convection air cooled (equipment is mounted on a cold plate cooled by conditioned air).

(d) Forced convection liquid cooled (liquid coolant pumped through the unit and then to a heat exchanger to dump the heat load).

(e) Thermo-electric cooling, using the Peltier effect, as in the familiar thermocouple. This has been used to cool hot spots in electronic systems.

For purposes of illustration, equipment cooling implementation on the E-3A and the F-15A will now be discussed.

E-3A Equipment Cooling:

E-3A equipment cooling uses two functionally identical forced air cooling systems, a draw through system, a liquid cooling system for the Surveillance Radar Functional Group and a mixed Antenna Pedestal Cooling System.

Selected avionics equipment is cooled by two separate, but functionally identical, forced air cooling systems utilizing recirculating air cooling loops with ram air as the heat sink. These systems are designated the forward and aft forced air cooling systems and are shown schematically in figures 8 and 9

(pages 31 and 32) respectively. Electric motor driven fans circulate cooling air through the avionics equipment and intercommencting ducting. During normal flight operations, the heat rejected by the avionics and absorbed by the recirculated air is rejected to ram air in a heat exchanger located in ram coolant air circuit. When the aircraft is unpressurized, ambient air is used directly or mixed with recirculated air as dictated by ambient air temperatures and avionics heat loads to cool the avionics equipment.

The draw through air cooling system (figure 10, page 33) is a controlled ventilation system which provides airflow across and through selected avionics equipment located in the main cabin, forward equipment bay, and the flight deck. Using cabin conditioning air as the cooling medium, air drawn through the equipment into a system of ducts and manifolds by a motor-driven fan (ground mode) or flow limiting venturi (flight mode).

The Liquid Cooling System (LCS) provides a temperature controlled flow of Ethylene Glycol Water mixture (EGW) to the surveillance radar transmitter. In flight, the heat in the coolant is rejected to the aircraft fuel through four liquid-to-liquid heat exchangers. On the ground the heat is rejected through a simple heat exchanger cooled by a ground cart. A schematic of the LCS system is presented in figure 11 (page 34).

The Antenna Pedestal Environmental Control System (APECS) is designed to dissipate the heat generated by the surveillance radar functional group (other than the surveillance radar transmitter) and by the Identification Functional Group (IFG) and associated equipment (figure 12, page 35). The APECS is a combination of a controlled air ventilation system, which provides airflow across selected avionics, and a liquid cooling system which provides temperature controlled flow of fluorocarbon FC-77 to other antenna pedestal avionics. After circulating through the liquid cooled avionics heat loads, the FC-77 is returned by a motor-driven pump and either passes through the air-to-liquid heat exchanger for cooling, or bypasses it, depending upon the temperature controller, to maintain proper coolant temperature (85 ± 5 degrees F). Air supplied to the heat exchanger and to provide convective cooling is either recirculated air or outside air.

In the recirculation mode, which uses the heat sink capacity of the antenna pedestal air and structure, air is drawn across the heat exchanger by fans and dispersed throughout the antenna pedestal cavity and ultimately returns through the fan. No outside air is introduced to the antenna pedestal cavity in this mode. In the outside air mode, air is drawn in through air inlet doors over the heat exchanger and through the fans before being discharged overboard. The APECS is designed to switch to the outside air mode when the FC-77 temperature approaches 90 degrees F. The ground cart mode is a modified outside air mode, the only

Note:
EX-Electronic Rack
HX-Heat Exchanger
⊖-Valve

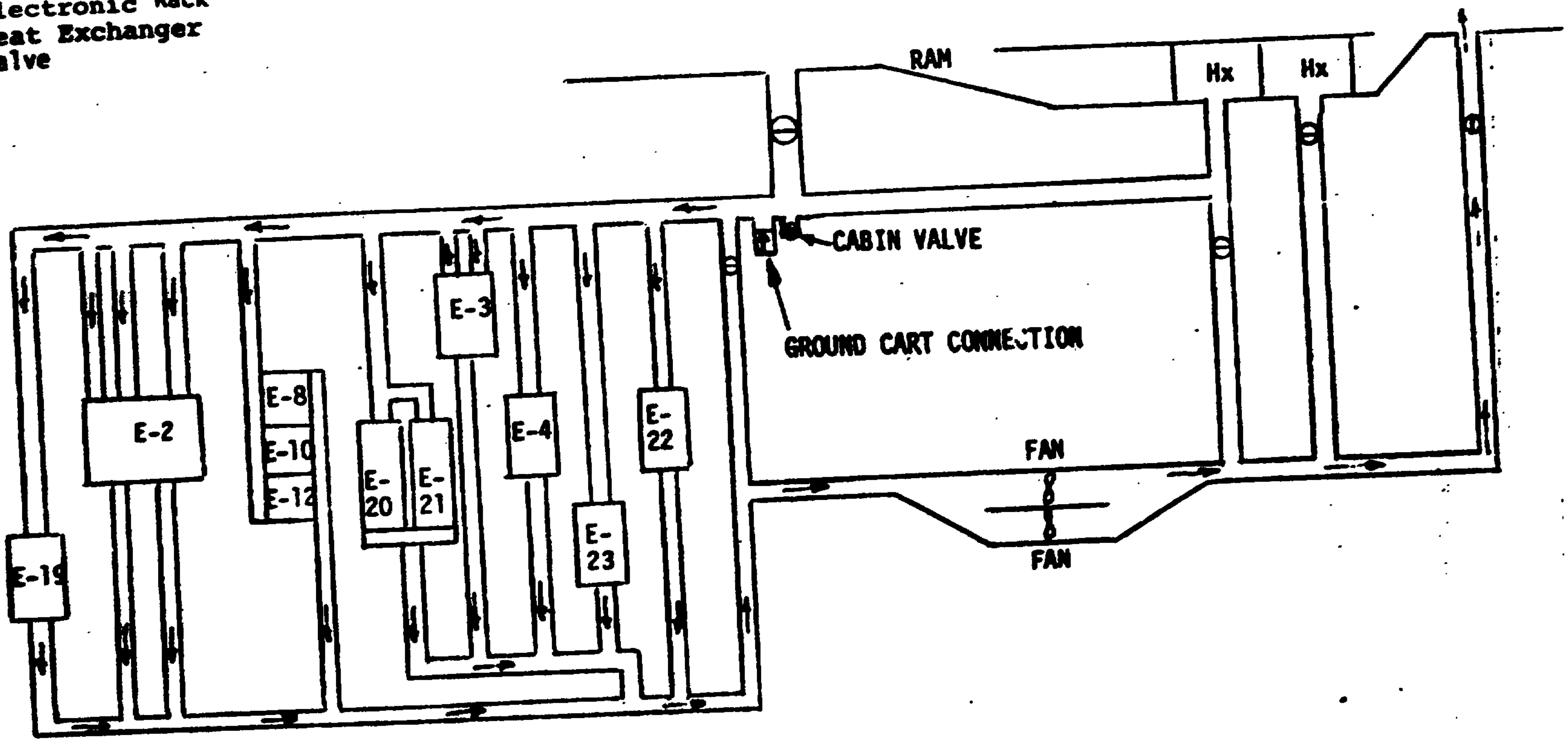


Figure 8 FORWARD FORCED AIR COOLING SYSTEM

Note:

E - Electronics Rack
⊖ - Valve
Hx - Heat Exchanger

RAD CONT - Radar Control
RAD PWR - Radar Power
RAD DR - Radar Drivers

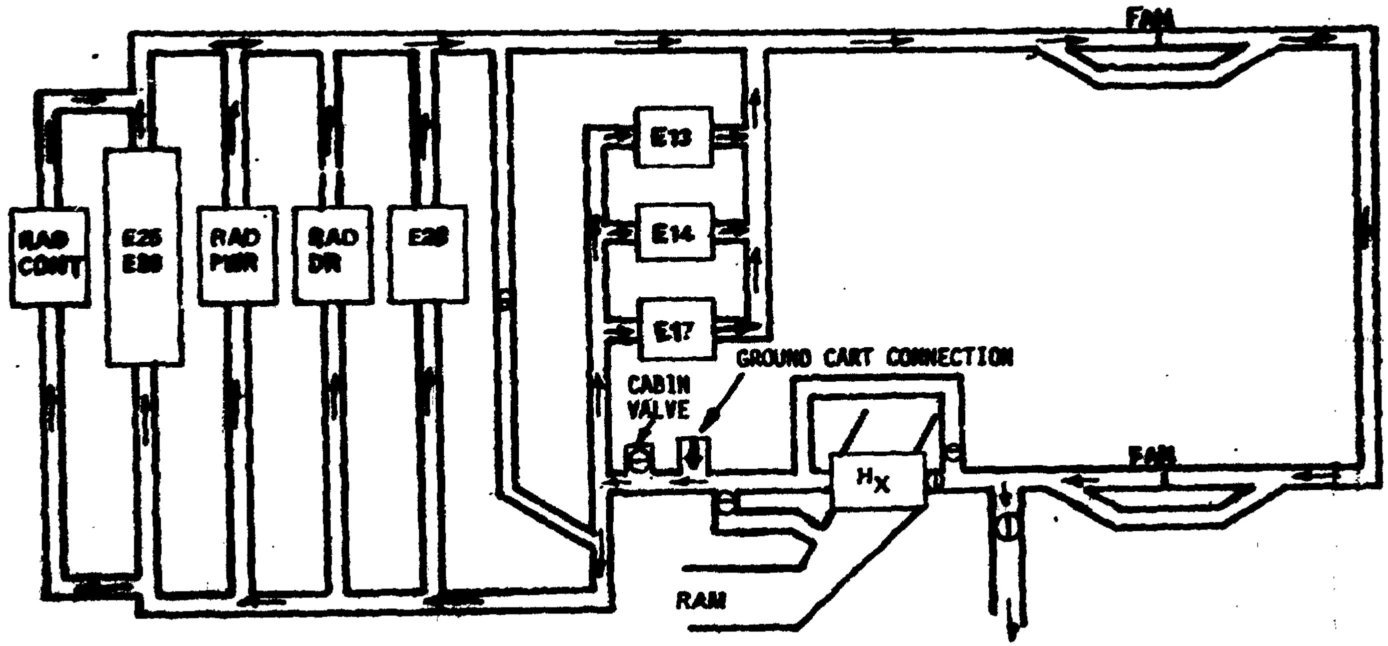


Figure 9 AFT FORCED AIR COOLING SYSTEM

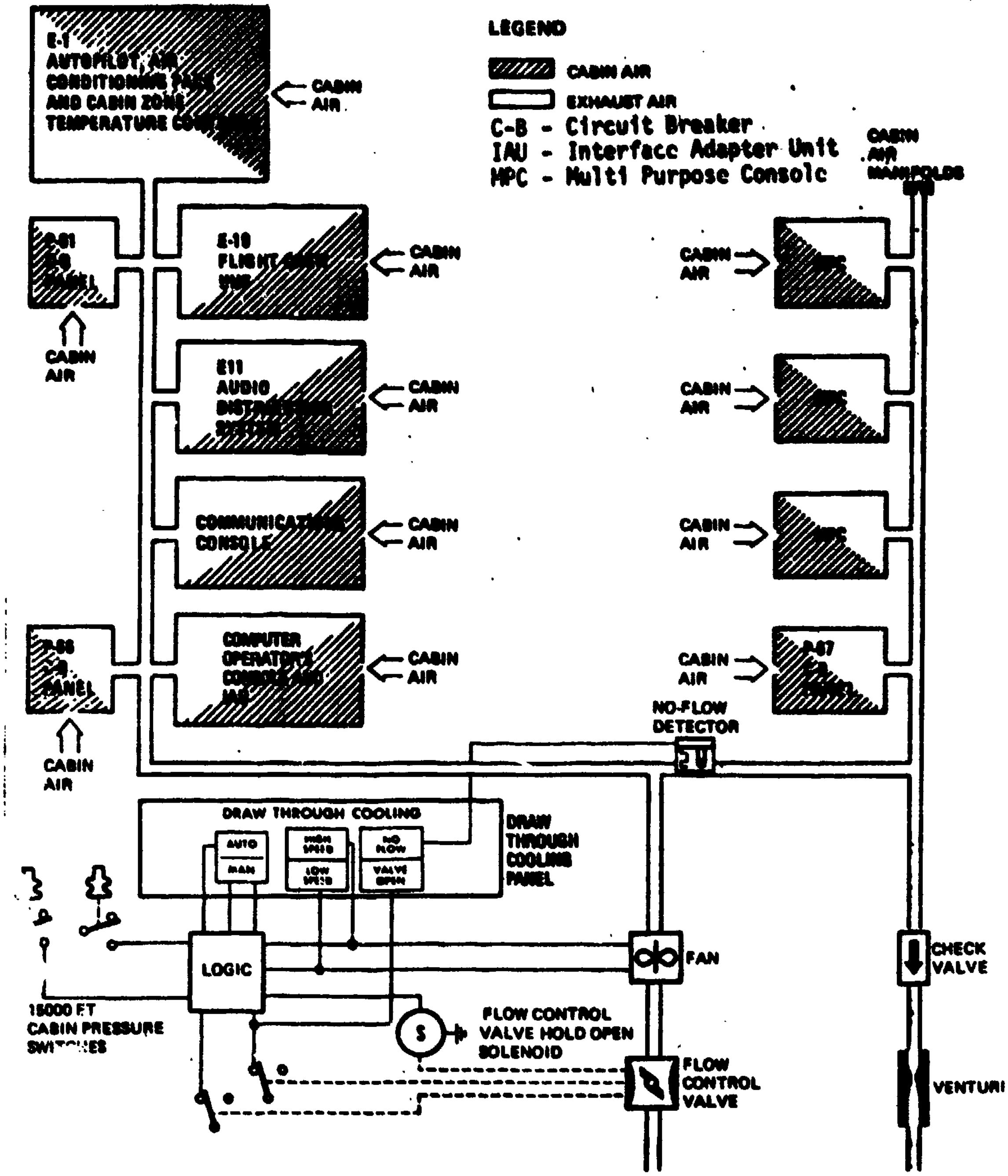


Figure 10 DRAW THROUGH AIR COOLING SYSTEM

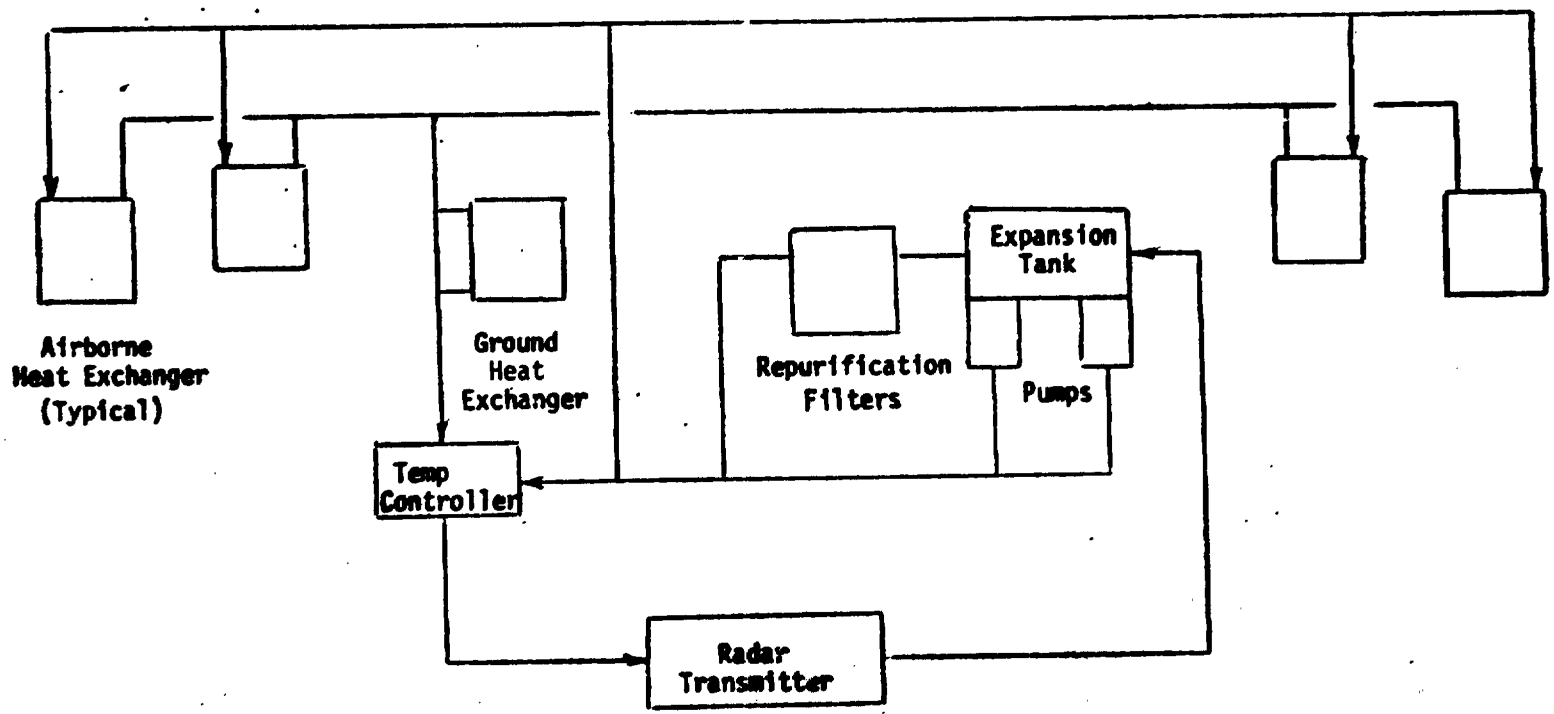


Figure 11 LIQUID COOLING SYSTEM

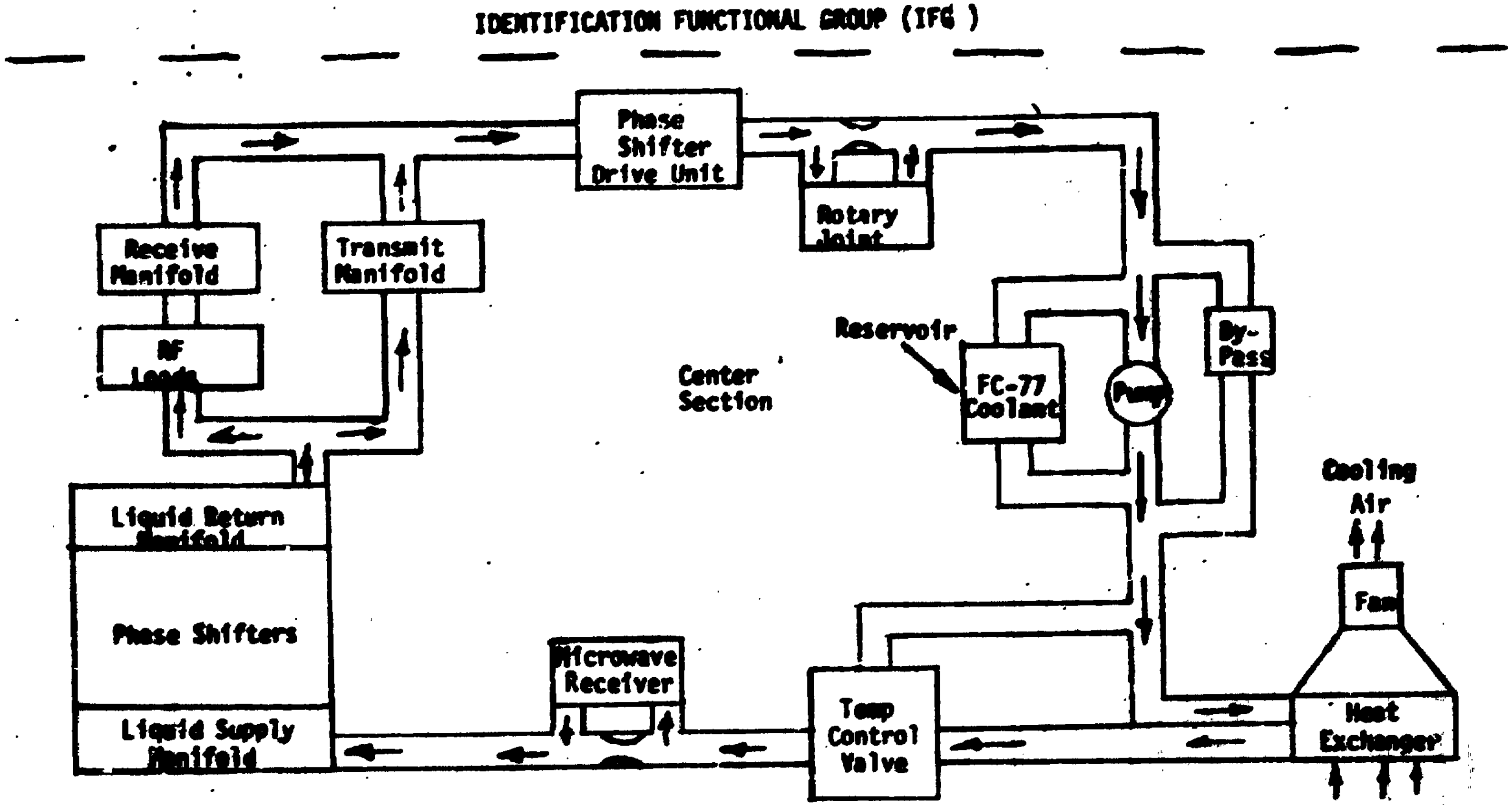


Figure 12 ANTENNA PEDESTAL COOLING SYSTEM

differences being that the air source is from an air conditioning cart and that some air is allowed to circulate within the antenna pedestal cavity before being expelled.

F-15A Equipment Cooling:

The schematic of the F-15A ECS in figure 7 (page 28) shows how the avionics cooling is arranged. Chilled air from the cooling turbine assembly is mixed with high pressure conditioned bleed air, the mix being controlled by the avionics flow control (item 6 in the figure) and the avionics temperature control (20). This conditioned air is used to cool the forward and aft avionics compartments and the internal countermeasures compartment, from which it is dumped overboard. The conditioned air on its way to these compartments is passed over a liquid to air heat exchanger which supplies coolant to the radar transmitter. Emergency ram air, if required, is admitted upstream of this heat exchanger and is passed over this and through the avionics compartments.

Other equipment on the F-15A is cooled by the fuel flowing to the engine (figure 13, page 37). If the fuel temperature leaving these radiators exceeds 195 degrees F additional fuel flow, limited to 10 gal/min per engine, is bypassed back to the internal wing tanks. This type of system can result in overheating of equipment during descent at low power or in case of engine failure.

ANTI-ICING, DEFROSTING AND DEFOGGING, RAIN REMOVAL

Anti-icing (prevention of ice build up) may be required for all portions of wings and stabilizers exposed to ice, on the engine air inlet (part of the engine system), on air scoops and on duct guide vanes (reference 5). Anti-icing, defrosting and defogging is required for all mission essential transparent areas. This includes, for example, areas needed for formation flying or for evasive action. Rain and snow removal is required for the windshield and for sensor windows. Salt spray removal and insect and dust removal (one 120 mg insect per 20,000 cubic ft) are required when the mission calls for low level flight over ocean and over land respectively.

Anti-icing of Non-Transparent Areas:

In general, anti-icing of flight surfaces is only required on aircraft which have to fly both low and slowly. As a result, full anti-icing of flight surfaces is rarely called for on Air Force aircraft. Anti-icing is usually limited to pitot systems, radomes (if ice would degrade effectiveness), essential air scoops and so on. If, however, anti-icing is required, then the following discussion applies.

LEGEND

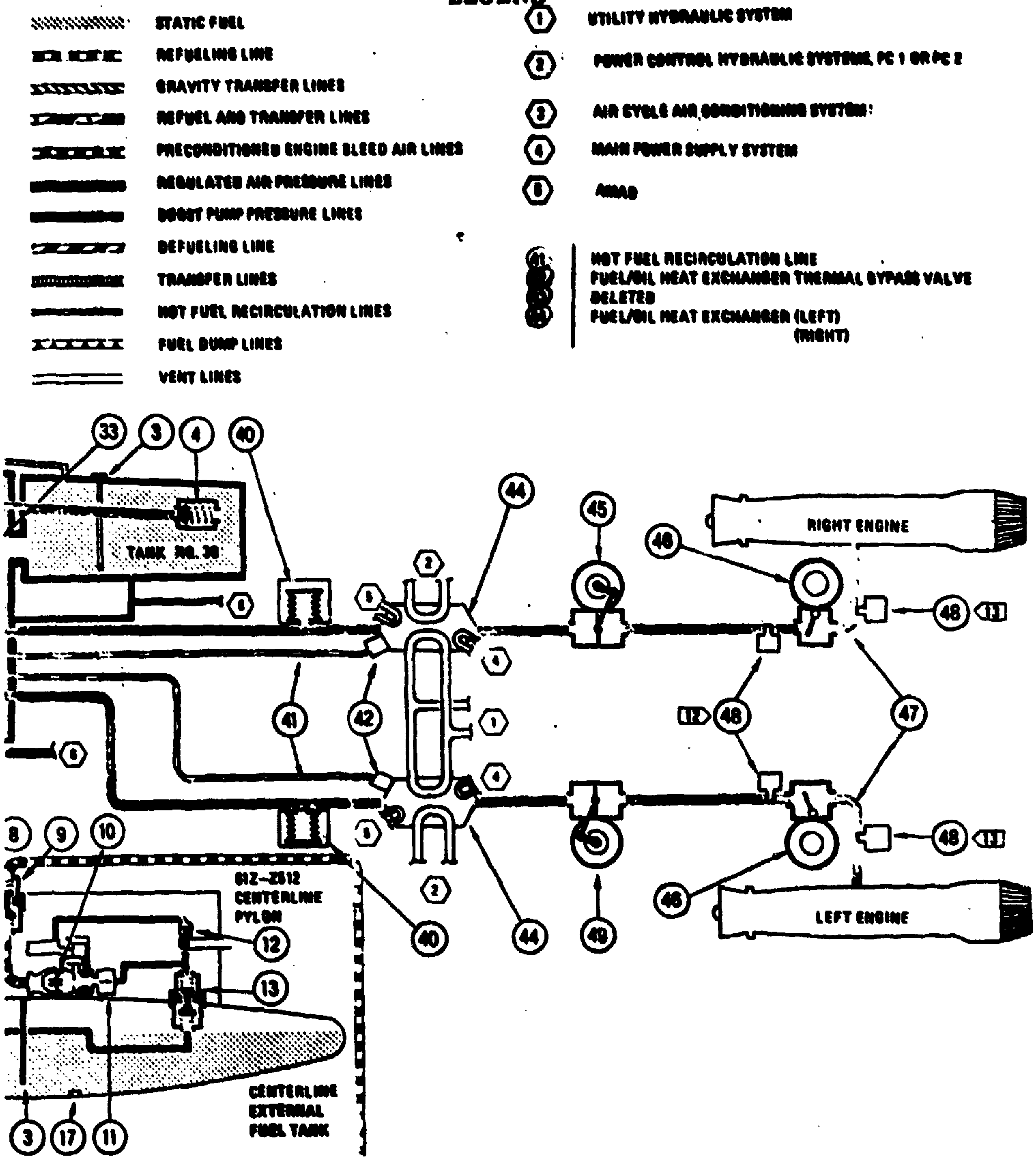


Figure 13 F-15A Fuel Cooling of Equipment

Anti-icing is required for the following representative flight conditions:

(1) Climb at speed for maximum rate of climb.

(2) Cruise at speed for maximum range at normal operating altitude, if that altitude is less than 20,000 feet.

(3) Descent (at speeds, rate of descent and engine power as recommended by the manufacturer, subject to approval by the procuring activity.)

If the design mission of the airplane requires intermittent operation below 20,000 feet typical conditions including the high and low extremes of speed are to be included as design points.

Surfaces to be provided with anti-icing are as follows:

(1) All portions of the wings and stabilizing surfaces which are exposed to ice.

(2) Engine inlets, antenna masts, hinge fairings, spoilers, dive brakes, struts and other ice accreting parts if required by either (a) the effect of ice accumulation on the normal functioning of the part or (b) the effect of increased drag on aircraft performance.

(3) Entrances to air scoops which must function during icing conditions, plus protection of guide vanes or at abrupt changes of direction.

Two levels of protection are required, "evaporative" and "running-wet". In the former, enough heat is supplied to completely evaporate ice over the impact area, while in the latter it is sufficient to prevent freezing over the area. For speeds less than curve A of Figure 14 (page 39) complete evaporation is required of all impinging water droplets at temperatures down to 15 degrees F unless the entire object is heated. In this case a running-wet surface is allowable with a minimum temperature of 35 degrees F at 0 degrees F ambinet temperature. For speeds greater than curve A but less than curve B the anti-icing system need only provide a running-wet surface at 0 degrees F ambient temperature since the runback should not freeze. For design speeds greater than curve B no anti-icing is required except for landing and take off.

Thermal anti-icing is usually used. Steady state hot air systems are usual but cycle electrical or cycle hot air systems may be used if designed and installed in accordance with an approved contractor specification. These systems are discussed in Part 3F of Reference 1.

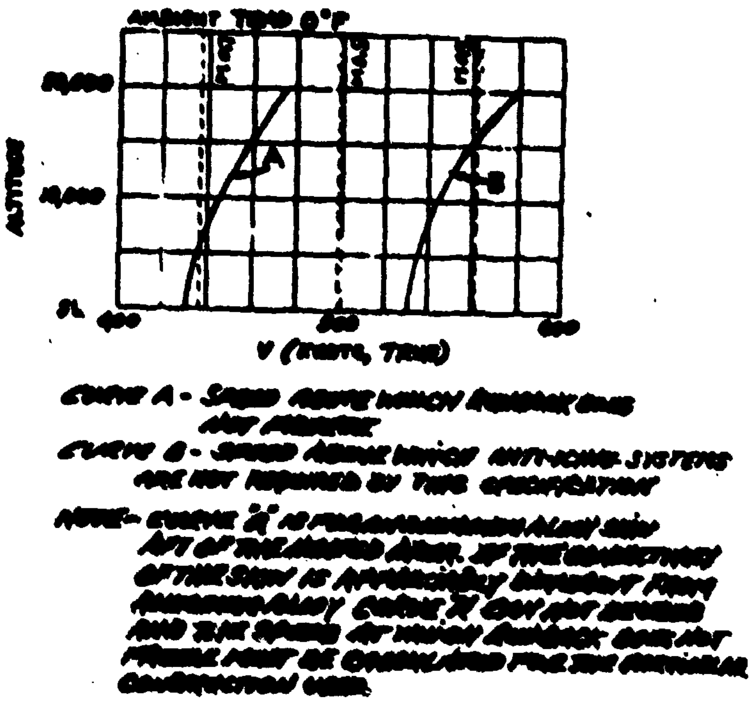


Figure 14 Effect of Speed on Icing Requirements

The usual approach for Air Force aircraft is to duct pre-conditioned air from the engine compressors through passages integral with the surfaces being heated. However, heat from a combustion heater or an exhaust heat exchanger may be used. Sufficient heat must be provided to ensure "evaporative" anti-icing or "running-wet" anti-icing over the area of impingement, depending on the speed at the relevant design point (figure 14, page 39). (In flight tests re-freezing has been encountered during run-back.) Computations must, of course, allow for heat losses in ducting and so on. Also, considerable care is required in ducting design to provide for the very wide temperature range between being inoperative in a cold environment and full operation.

Cyclic de-icing heats strips of the surface, approximately perpendicular to the airflow, in a sequential manner so as to shed the ice from front to back. Electric cyclic de-icing is used for propeller and rotor blades. The electrical heaters usually consist of heater ribbons embedded in a dielectric over the base skin, covered by metal cladding for protection. Electric heat is convenient for relatively small, remote items such as antenna masts.

Anti-Icing of Transparent Areas:

The windshield is to be thermally anti-iced by hot air, or electrical conductive coatings (references 5 and 6). Other mission essential transparent areas are to be anti-iced by hot air, electrical conductive coatings, liquid spray or extendable shields or deflectors. The most usual method uses external hot air jets (figure 15, page 41), but electrical conductive coatings are also fairly common. In the latter, the conductive layer is part of the windshield lamination. This approach also assists with defogging of the interior of the windshield.

Defrosting and Defogging:

Defrosting and defogging is required for all mission essential transparent areas, including areas required for taxiing, evasive action, formation flying, scanning and sighting stations, astro domes, camera windows, areas required to check engine operation, control surfaces etc. Defrosting and defogging may be by hot air jets, double panes with hot air between panes, double pane with dry air insulating gap, electrically-conductive coatings, humidity control of cabin air, or any combination of these methods. Protection is required during rapid descent after cold soak at high altitude (a stressing case) and in flight at constant altitude.

Double panes with hot air between are susceptible to accumulation of dust, dirt and oil and to heat stress problems and are rarely used. Double panes with dry air insulating gap may be convenient for flat surfaces, especially when combined with humidity control of cabin air. Electrical heating also is

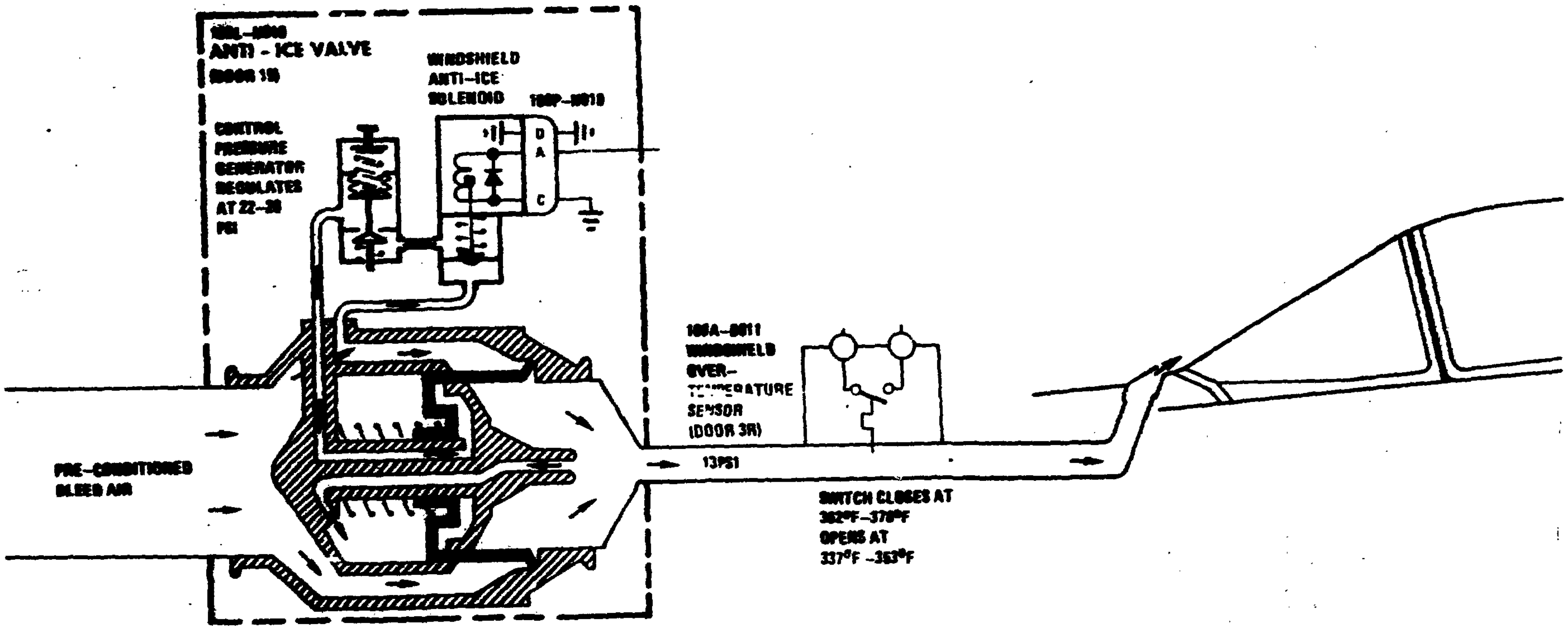


Figure 15 F-15 Anti-Ice System

good for flat surfaces, and can accomplish anti-icing as well as defrosting. However, the most common approach an Air Force aircraft is to use hot air jets across the inside surfaces, provided from engine bleed air with temperature control to prevent overheating of the transparency and reduce crew discomfort.

One commonly used system uses conditioned cabin air diverted from the cabin inlet duct (figure 16, page 43). The anti-fog air continuously passes through the anti-fog heat exchanger. Hot air, taken from the preconditioned bleed air, enters the heat exchanger, transferring heat to the anti-fog air. The air is ducted to the base of the windscreen and forced through small orifices, towards the inner surface of the windscreen.

Removal of Rain, Insects, Salt and Dust:

Provisions are required (reference 5) to clear enough of the pilot and co-pilot's windshield to provide an adequate field of vision in "heavy" rain (0.59 inches per hour, 1500 micrometer median droplet diameter) and in snow for

(a) Ground taxi

(b) Take-off

(c) Landing approach

(d) Landing

(e) In-flight refueling if this is to be accomplished below 20,000 feet

(f) Level flight at 1.6 times the stall speed at maximum weight with flaps and gear retracted for fixed wing aircraft

(g) Maximum cruise speed for rotary wing aircraft sufficient clearance is also requested to enable a safe landing in "excessive" rain (1.6 inches per hour, 2300 micrometer median droplet diameter)

Removal of insects and dust is required when aircraft missions require low level flight over land, removal of salt spray for low level flight over ocean or along the coast. Vertical landing and take off aircraft require dust removal. Removal of dust, insects and salt spray is accomplished by a washing system.

Methods used for removal of rain and snow include a ground applied repellant which facilitates removal of intercepted rain by the slipstream, jets of preconditioned bleed air and in-flight applied repellant. An effective approach used in Air Force aircraft is a combination of air jets with in-flight applied repellant.

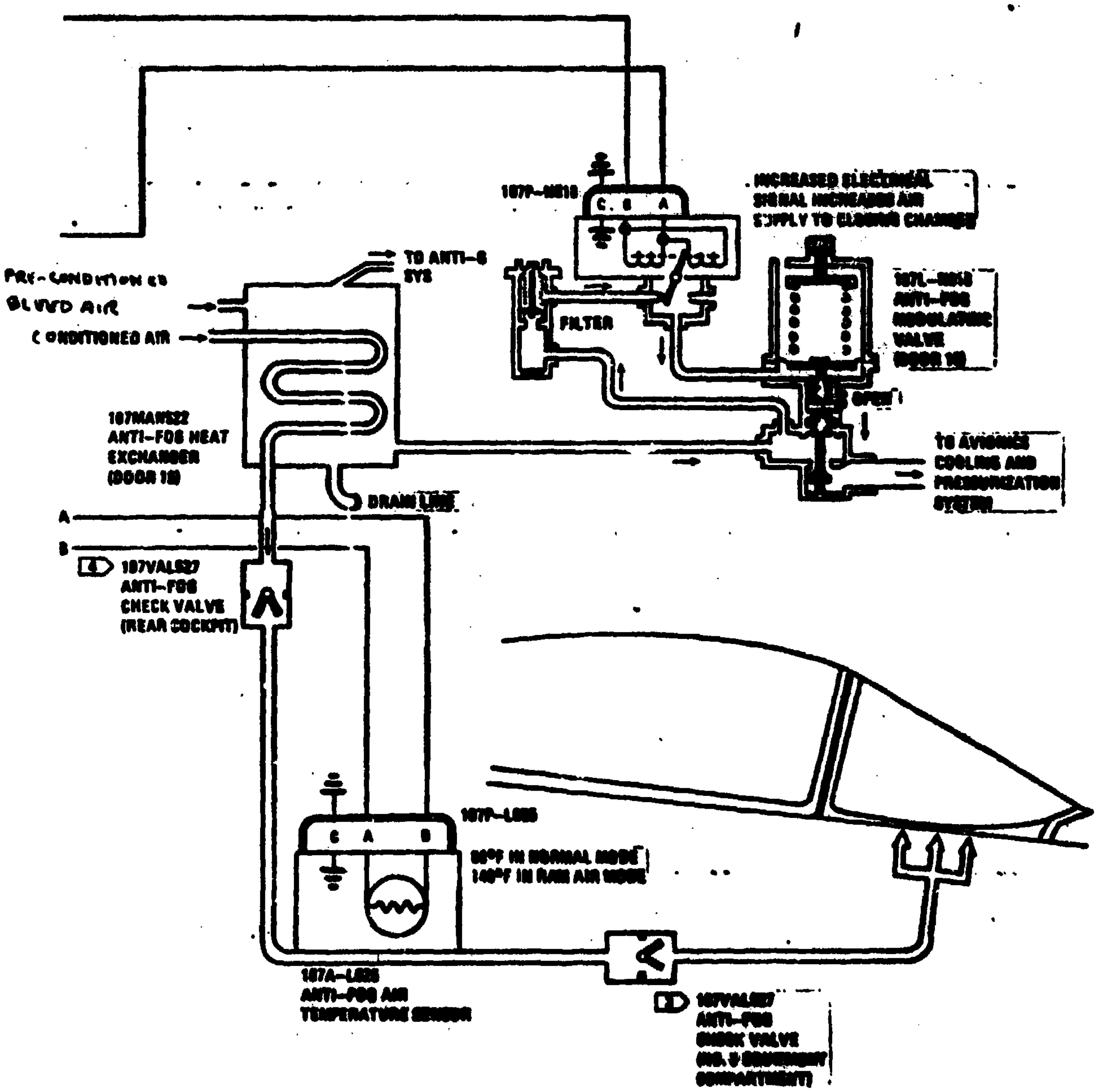


Figure 16 F-15 Anti-Fog System

OXYGEN SUPPLY

Oxygen supply may be from a liquid oxygen converter or gas cylinders. Passenger supply may be from chemical oxygen converters with the approval of the procuring agency. Oxygen systems use standard, tested components, with layout and connections adapted to the particular aircraft. Hence AFFTC evaluation is primarily directed at ensuring that the system is well laid out, functions correctly and is easy to service and maintain.

A liquid oxygen system is automatically operated by controlling the rate of evaporation of liquid oxygen with pressure operating valves. Evaporation of liquid oxygen is accomplished by adding heat to the liquid which causes it to expand and therefore, raise the pressure. A buildup and warming coil is incorporated in the system, which provides the necessary heat transfer to the liquid. The pressure control valve provided in the converter controls the rate of evaporation during flow. A relief valve is provided to relieve excess pressure caused from repeated cycling or low demand on the system.

When the system is filled from the servicing trailer, coupling of the hose to the fill, build-up and vent value operates a plunger which opens the valve to the overboard vent. Liquid oxygen is added until it spills from the vent. (figure 17, page 45). In the pressure buildup phase a heater in the buildup and warming coil vaporizes oxygen until approximately 72 psi is reached, at which time the pressure control valve prevents further fast liquid evaporation.

Operation begins during the pressure buildup phase and continues until all liquid oxygen has evaporated. Liquid oxygen is drawn through the orifice flow modulator to a heat exchanger, which vaporizes the oxygen and brings it to a useable temperature, and on to the diluter demand oxygen regulator.

The diluter demand oxygen regulator automatically mixes air and gaseous oxygen at a ratio dependent upon cabin altitude and delivers this mixture at the proper pressure to the crewmember's oxygen mask upon demand. With the diluter demand oxygen regulator ON/OFF valve lever set at ON and the 100 percent - NORMAL selector in the NORMAL position, the regulator will furnish diluter oxygen at altitudes up to 30,000 feet. With a tight, properly fitting oxygen mask, the regulator can be used at altitudes up to 48,000 feet with the 100 percent - NORMAL selector in the 100 percent position. The regulator is capable of handling oxygen inlet pressures of 50 to 500 psi. The oxygen supply pressure gauge range is from 0 to 500 psi. The regulator contains its own inlet filter.

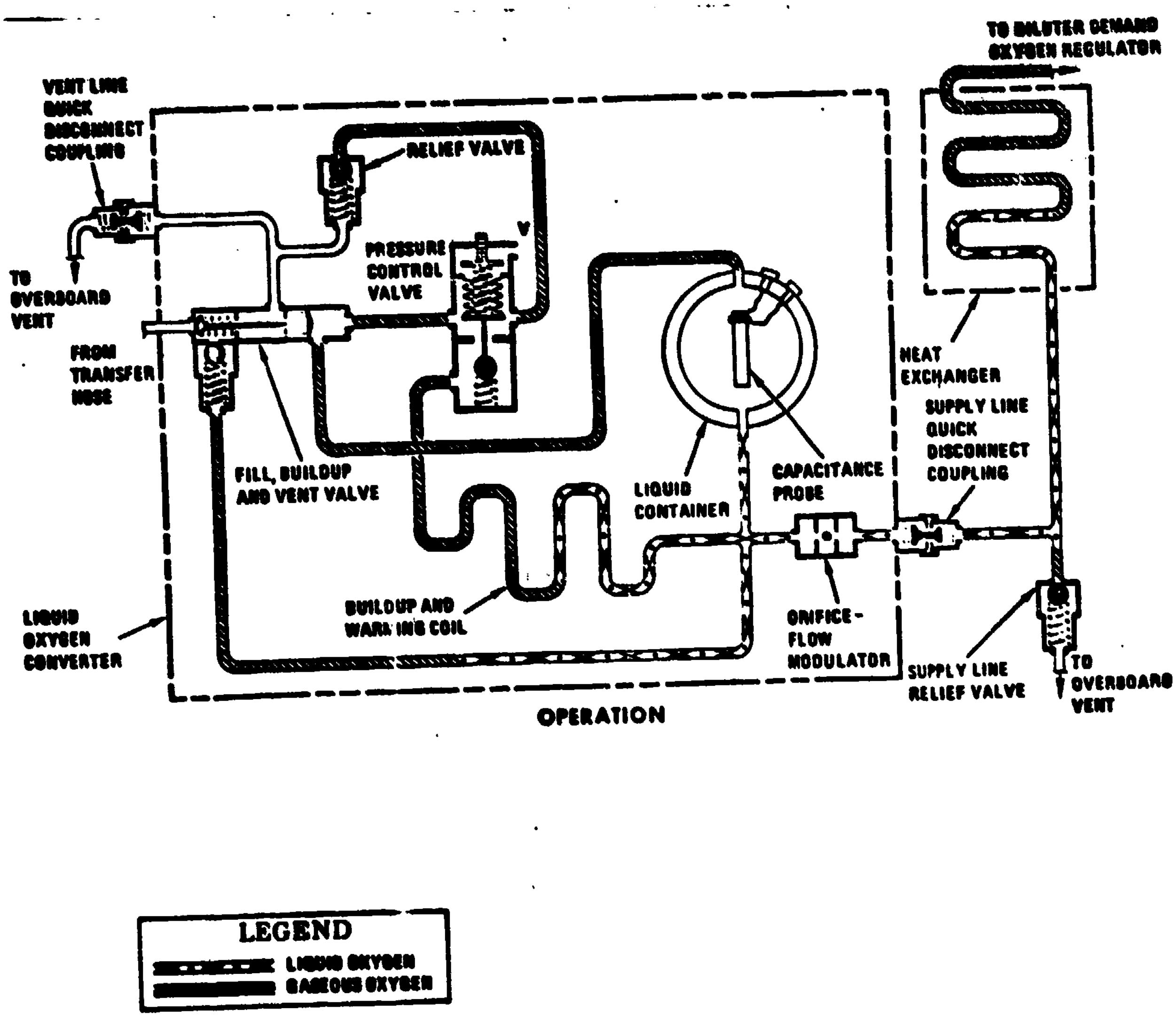


Figure 17 Schematic of Liquid Oxygen Convertor

In situations where the oxygen supply is from a liquid oxygen converter, the diluter demand oxygen regulator will furnish an emergency nondiluted supply of oxygen to the crewmember's mask. By placing the EMERGENCY-NORMAL-TEST MASK selector to the EMERGENCY position, 100 percent oxygen coupled with an increase in pressure is automatically supplied to the crewmember (100 percent oxygen will be furnished regardless of the position of the 100 percent - NORMAL selector). This emergency function of the regulator can be utilized in situations such as loss of a canopy in-flight, smoke in the cockpit, suspected insufficient normal oxygen supply or explosive de-compression.

REQUIREMENTS AND PROBLEM AREAS

The ECS is a quite complex system charged with a wide range of support functions such as supplying pressurization to fuel tanks, air conditioning of occupied compartments and equipment compartments and anti-icing. Some of these functions are straightforward and rarely troublesome but others such as air conditioning are complex and are frequent sources of problems.

The ECS is designed to a combination of general specifications and specifications peculiar to the individual aircraft type. Requirements relating to human tolerances can be generalized, but those related to support of other subsystems and equipment are, naturally, peculiar to the individual design. It is the important function of the systems integration engineer in the design process to define these "interfaces" between subsystems. For the AFFTC flight test engineer evaluating an ECS, this means that he must familiarize himself with the contractor end item specifications.

Specifications are written primarily for use of the supplier and the contracting agency. They therefore, contain a mass of design requirements covering a high degree of detail. The flight test engineer evaluating the end product is usually concerned with a small proportion of these requirements. In this Section we will review and summarize those requirements which appear to be of most concern to him and also review problem areas commonly encountered in each area. This is a task which:

a. is impossible to do in a really adequate manner and

b. even if done perfectly, would rapidly become out of date.

It is, therefore, most important that the flight test engineer use this Section only to get the general flavor of the environment in which he is working and do his own research on the particular item he is tasked to evaluate.

The general specification covering performance, design and testing requirements is MIL-E-38453A, "Environmental Control, Environmental Protection, and Engine Bleed Air Systems, Aircraft, General Specification For". Supplementing this are specifications for components such as air cycle air conditioning subsystems, anti-icing equipment, defogging of transparent areas, electronic equipment and so on. These will be referenced at appropriate places below.

Considerable attention will necessarily be given to testing against these specific requirements, but evaluation of operational suitability must also be kept in mind. The ECS should be designed to minimize crew distraction and workload. Similarly,

field servicing should be fast, simple and as error-proof under stress as is reasonably feasible. The ECS flight test engineer should seek comment from flight crews with operational experience and continously encourage ground crews to evaluate the aircraft as an operational system.

Evaluation of an ECS, in general, involves a substantial contribution from the Reliability and Maintainability and the Human Factors Branches of Airframe Systems Division. The flight test engineer who is tasked with evaluating the ECS as a whole must recognize the cooperative nature of the effort and do his part to ensure that in this cooperation no areas are missed and that all available expertise is applied.

We will now briefly discuss requirements and potential problems in the following areas:

a. engine bleed air system

b. pressurization of occupied compartments

c. equipment pressurization

d. supply of pressurization to reservoirs, inflatable seals and suits

e. air conditioning of occupied compartments

f. equipment conditioning

g. anti-icing of non transparent areas

h. anti-icing of transparent areas

i. defrosting and defogging of transparent areas

j. removal of rain and snow from transparent areas

k. removal of insects, salt and dust from transparent areas

l. oxygen supply

As would be expected from the length of the above list, this discussion is inevitably repetitive and boring. It is strongly recommended that the reader pass over the detail somewhat lightly on his/her first reading.

ENGINE BLEED AIR SYSTEM

This system consists of all the ducting and components that pass high or low pressure bleed air from the engine ports or other compressed air sources to all components requiring bleed air at the temperatures, pressures and weight flows required by each component. Requirements are summarized in Tables A1A and A1B (pages 91 and 92). In terms of performance it must be able to supply all equipment requiring simultaneous supply. Design requirements mostly address the problems and danger of having ducts carrying very hot, high pressure bleed air in what can be a cold airplane. For example, the duct temperature before start up may be as low as -65degrees F. Particular points to be checked are

a. shut off valve locations and design (e.g. normally open, fail open at each bleed air source)

b. adequate protection of personnel from hot ducts

c. safe couplings at joints (safety latches are required where the bleed air temperature normally exceeds 450 degrees F)

The engine bleed air system is not a source of many problems in ECS installations except for cases of oil smoke and fumes in the blood air. Although the cause of such smoke and fumes is an engine deficiency, the result has been serious ECS problems on recent flights with fumes in the cockt, oil in the water coalescer unit and oil over electronic equipment.

PRESSURIZATION OF OCCUPIED COMPARTMENTS

Most requirements for pressurization are contained in MIL-E-38435A, which covers environmental control systems as a whole. Additional requirements relating to air cycle air conditioning systems, primarily to design, are contained in MIL-A-83116A.

Performance and Functional Requirements:

Those performance and functional requirements which appear to relate most clearly to AFFTC test and evaluation are summarized in Table A2A (page 93). Briefly, these cover the following:

1. Altitude is to be selectable between -1000 and +10,000 feet for cargo and personnel transports, navigation trainers and early warning aircraft but with a limit on differential pressure. For other types, altitude control is to be automatic with 8000 feet maximum altitude, with with possible limit of 5 psi differential pressure.

2. Accuracy is to be within ± 0.4 inches Hg of nominal when the compartment is pressurized. There are limits on overshoot, fluctuations and transients when engine settings are changed.

3. Rate of Change is to be selectable for cargo etc. types. Limits are stated for others.

4. Excess differential pressure is to be prevented by safety valves.

5. Opening of doors, hatches etc must be safe.

6. Normal and emergency release procedures are to be provided.

7. Available flow must be adequate to overcome allowable uncontrolled leaks, maintain schedule and provide required ventilation rate.

8. Emergency enclosed systems shall have a separate pressurization source for use during the escape sequence.

Design Requirements:

The design requirements which appear to relate most closely to AFFTC test and evaluation are summarized in Table A2B (page 95). These cover the following:

Pressurization Source.

Compartment air conditioning air is preferred, but temperature controlled bleed air is the next choice.

Multiple Sources and Single Failures.

At least two pressurization sources are to be provided an multi-engined aircraft, each capable of providing the required pressurization. No single failure is to result in the occupied compartment pressure altitude exceeding 14,000 ft.

Check Valves.

Check valves are to be provided to prevent rapid loss of pressure in case of air source failure.

Regulators, Safety Valves and Blow-out Panels.

At least one regulator is required in each separately controllable compartment. Safety valves are to protect against excessive positive or negative differential pressures. Blowout panels or adequate flow areas must be provided between compartments. Discharge ports must not be subject to adverse weather. No single failure shall result in failure of both pressure regulator and safety valve.

Instruments and Controls.

Caution indicators are to be provided to show loss of compartment pressure. Crew station controls are to be provided for pressure release. Crew station controls to control and instrumentation to measure cabin pressure and rate of ascent or descent are required for cargo and personnel transports, navigational trainers and early warning aircraft.

Discussion:

As will be seen, the requirements on the pressurization system are rather simple and straightforward. A potential problem area in high performance aircraft is excessive sensitivity to changes in engine setting (for example, changes in cockpit altitude of 5000 to 10,000 feet with change of engine power settings experienced on a fighter aircraft). Limitation of the effects of single failure and clear, effective controls are both very important. These are primarily the domains of Reliability and Maintainability and Human Factors personnel, but the ECS flight test engineer should take an active interest in these areas from the functional aspect and encourage attention to them by flight and maintenance personnel.

SUPPLY OF PRESSURE TO EQUIPMENT, RESERVOIRS, INFLATABLE SEALS, SUITS

These are briefly summarized, from the point of view of evaluation flight test, in Tables A3 and A4 (pages 97 and 98). In general the environmental needs of equipment vary widely and cannot be standardized in the way that those for the human body must be. Hence the general requirements largely refer their reader to equipment specifications or the general aircraft specifications. In these areas it is the very important design task of the aircraft systems engineer (not always well executed) to define the "interfaces" between the environmental control subsystem and the units it serves. Correspondingly, the AFFTC evaluation test engineer should make himself familiar with the end item specifications and operational requirements which the particular ECS is supposed to meet. He should get the operational requirements from AFTEC or from the using Command.

General requirements include the following:

1. When two or more units are pressurized by the same source, loss of pressurization by one shall not cause loss of pressurization to others.

2. Automatic regulation is required to ensure pressures compatible with pressurized units/the most critical unit in pressurized compartments.

3. Protection by safety valves is required against excessive positive or negative differential pressures.

4. Fail-safe means shall be provided to prevent entrance of hazardous fumes into environmental control, environmental protection or engine bleed air systems.

5. Anti-g suit air is to be between 50 degrees F and 130 degrees F, pressure suit air supply between 55 degrees and 90 degrees F.

6. If a single failure can create the possibility of excessive fuel tank air temperatures, means shall be provided of indicating excessive temperatures to the crew.

In addition to these general requirements some systems have limitation on dust and other contaminants to reduce internal deposits.

Analysis of the potential effects of single failure is primarily the responsibility of the Realiability and Maintainability Branch of Airframe Systems Division and of the Unit Systems Safety Officer (USSO) but the ECS test engineer should take an active interest in this area and will be requested to support the USSO. In particular, he should ensure that any instances of single failure are reported and analyzed.

The contractor Failure Modes and Effects Analysis will provide a valuable review of potential failure modes and their impact and will greatly assist in identification of tests which should be made of ECS operation with partial failure.

AIR CONDITIONING OF OCCUPIED COMPARTMENTS

This is a complex and demanding function and is understandably a major source of problems and deficienes in ECS evaluations. Performance and functional requirements are summarized in Table A5A (page 100) and design requirements in Table A5B (page 102) (with some overlapping).

Perfromance and Functional Requirements:

The requirements from Table A5A may be further summarized as follows:

1. Ventilation rates are to be at least 20 cubic feet per minute (cfm) per man for all operating conditions and at least 1.8 times the maximum allowable production leakage rate for all pressurized operations. Air velocities near seated personnel are not be exceed 300 feet per minute (fpm).

2. Radiating surfaces are not to exceed 105 degrees F near seated personnel during pressurized flight, 140 degrees F for all other locations and conditions.

3. Air supplied to the occupied compartments is to be free of excessive moisture.

4. Air supplied to the occupied compartments is to be free of excessive contamination.

5. The automatic temperature control is to maintain the average compartment air temperature to within ±3 degrees F of selected settings. Temperature variations between any two points in a seating envelope should not deviate more than ±5 degrees F from the average cabin temperature. Temperature differences outside the envelope are not allowed to vary more than ±10 degrees F average cabin temperature.

6. Floor temperatures are to be maintained above 60 degrees F average, with no location less than 40 degrees F.

7. Average cabin temperatures are to be maintained between 45 degrees F and 90 degrees F for unpressurized flight and between 70 degrees F and 90 degrees F during flights with an inoperative air conditioning module.

8. The cooling equipment is to have sufficient capacity to maintain average compartment temperature at 70 degrees F except that it may be 80 degrees F for transients lasting less than 30 minutes.

9. Heating equipment is to be capable of maintaining an average compartment temperature of 80 degrees F.

Design Requirements:

These are quite largely maintainability and servicing requirements (Table A5B, page 102). In addition to those referred to in Table A5B there is a host of requirements on choice of materials and so on which concern the contractor and the procurement agency rather than the AFFTC engineer, who is evaluating the end product. If, however, a problem is encountered such as corrosion or freezing of valves and controls he should review MIL-E-38453A (reference 5) and MIL-A-83116A (reference 7) to find out exactly what requirements the system is failing to meet.

Discussion:

The following are representative examples of air conditioning system deficiencies, taken from fairly recent tests on a large surveillance aircraft and on a high performance fighter.

On the surveillance aircraft the following were the primary problems:

1. Excessive condensation in cabin under humid conditions

2. Uneven distribution of conditioned air (nozzles redesigned)

3. Excessive vertical temperature gradients in cabin on cold days; cold floors.

4. Slow stabilization of cabin temperatures on ground after cold soak.

On the fighter aircraft the primary problems were as follows:

1. Pilot had hot head and cold feet at high altitudes.

2. Smoke and fumes in cockpit, from engine oil leak into bleed air.

3. Water droplets sprayed over pilot under humid conditions.

It will be seen that these deficiencies are rather straightforward in nature and readily detected either in normal operation or in tests in air with high water content and/or at extreme temperatures. Inadequate water separation and poor temperature distribution are the primary, recurrent performance problems. Another quite frequent problem is that of excessive noise from the air cycle machine and in the ducts.

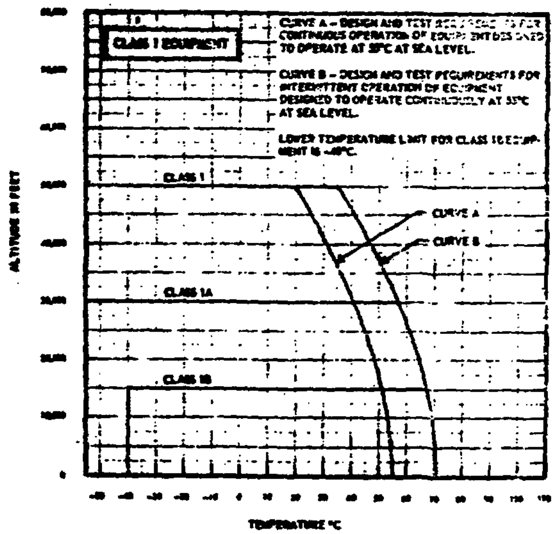
Evaluation of the air conditioning system against design requirements involves the expertise of Human Factors and Reliability and Maintainability Branches and should be a cooperative effort.

EQUIPMENT CONDITIONING

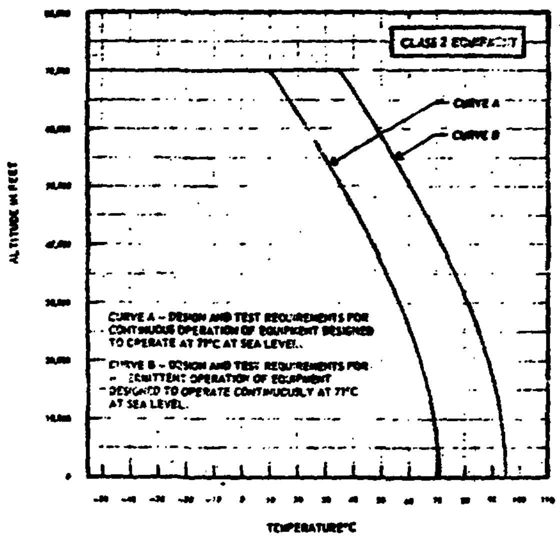
Equipment conditioning requirements are summarized in Tables A6A (Performance and Functional Requirements, page 104) and A6B (Design Requirements, page 107). Equipment cooling needs cover a very wide range, from those which can be met by free air convection to those which require forced convection liquid cooling.

<u>Performance and Functional Requirements</u>:

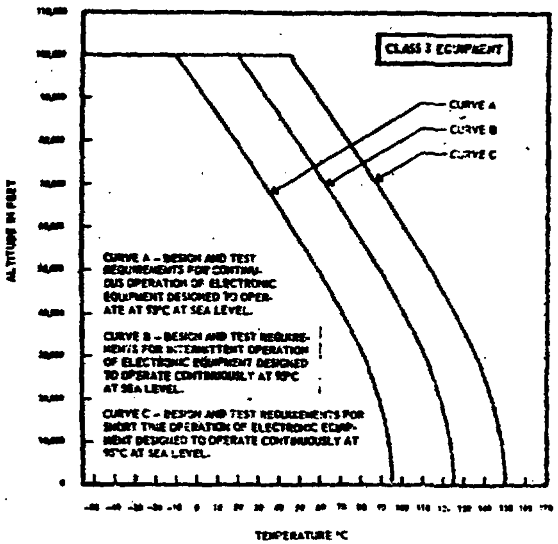
If the equipment is to use free convection air cooling it must conform to general standards defined in MIL-E-5400T (reference 8). These are grouped into the following classes, Class 1 being assumed unless one of the others is specified. More detail of the requirements for each of these classes is given in Table A6C (page 108) and Figure 18 (page 55).



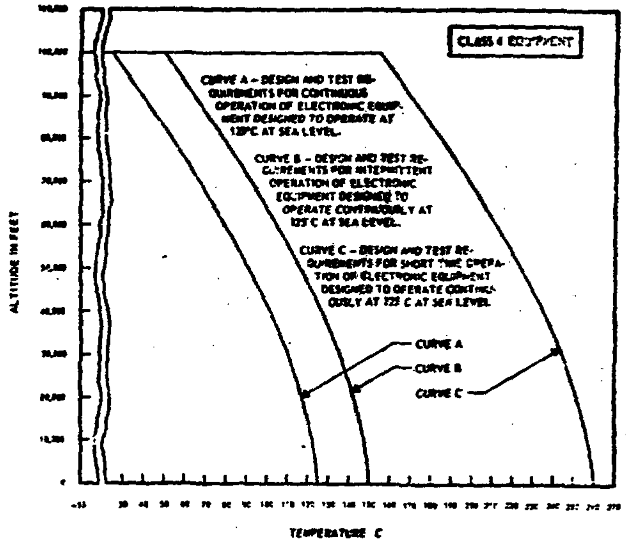
Operational requirements for class 1 airborne electronic equipment (temperature vs. altitude)



Operational requirements for class 2 airborne electronic equipment (temperature vs. altitude).



Operational requirements for class 3 airborne electronic equipment (temperature vs. altitude)



Operational requirements for class 4 airborne electronic equipment (temperature vs. altitude)

Figure 18 Operational Requirements for Convection Cooled Electronic Equipment

Class 1 - Equipment designed for 50,000 ft altitude and continuous sea level operation over the temperature range of -54 to +55 degrees C (+71 degrees for intermittent operation).

Class 1A - Equipment designed for 30,000 ft altitude and continuous sea level operation over the temperature range of -54 to +55 degrees C (+71 degrees intermittent operation).

Class 1B - Equipment designed for 15,000 ft altitude and continuous sea level operation over the temperature range of -40 to +55 degrees C (+71 degrees intermittent operation).

Class 2 - Equipment designed for 70,000 ft altitude and continuous sea level operation over the temperature range of -54 to +71 degrees C (+95 degrees intermittent operation).

Class 3 - Equipment designed for 100,000 ft altitude and continuous sea level operation over the temperature range of -54 to +95 degrees C (+125 degrees intermittent operation).

Class 4 - Equipment designed for 100,000 ft altitude and continuous sea level operation over the temperature range of -54 to +125 degrees C (+150 degrees intermittent operation).

Class 5 - Equipment designed for altitudes greater than 100,000 ft for periods of time not exceeding 6 hours, and continuous sea level operation over the temperature range of -54 to +95 degrees C (+125 degrees intermittent operation).

These standards correspondingly define the performance required of the equipment air conditioning system. More detail is given in Table A6C and Figure 18.

For the other types of cooling (internally forced air, cold plate forced convection air and forced convection liquid) the equipment air conditioning system must provide cooling fluid temperature and weight flow called for in each equipment specification. Hence the ECS flight test engineer needs to have data from these specifications available.

Design Requirements:

Relevant design requirements are reviewed in Table A6B (page 107). It will be seen that these are somewhat general in nature. There are, of course, a large number of detail design requirements on, for example, air cycle air conditioners supplying the conditioned air used to cool the equipment, but these primarily relate to detailed design and will not normally concern the ECS flight test engineer.

Discussion:

Equipment cooling requirements can be quite complex and demanding. As a result they are a frequent source of deficiencies. Some of these can result from inadequate or outdated interface

definitions by the prime contractor. The AFFTC engineer conducting ECS evaluations should have available the end item specification to which the ECS is designed and also, if possible, the equipment specifications for items not using free convection cooling.

Much of the equipment is critical to a successful mission and some may be important for safe recovery. It is, therefore, very important in testing and evaluation of equipment cooling to consider the operational profile of the weapon system as well as the legal requirements of the specifications. For example, if important communications equipment cannot be used during taxi and take-off this may seriously degrade operations regardless of what the specifications may say. Such restrictions should be identified and their impact on operational effectiveness evaluated.

ANTI-ICING OF NON-TRANSPARENT AREAS

Performance and functional requirements are reviewed in Table A7A (page 109) and design requirements in Table A7B (page 111). In general de-icing of flight surfaces is only required on aircraft which have to fly both low and slowly. As a result, full de-icing of flight surfaces is very rarely called for on Air Force aircraft. It is perhaps significant that the requirements date from 1954 and from 1971.

If such a capability were called for, MIL-A-9482 (reference 9) paragraph 4.2 requires that the contractor conduct tests in dry air "unless otherwise specified by the procuring activity to demonstrate control system operation, temperature indication operation, operation of overheat warning and control, freedom from overheating and detrimental effects of thermal expansion. In addition, a complete thermal survey is to be conducted to determine the heat available". See Table A7C (page 112) for details. In addition MIL-E-38453A, of a later date, calls for demonstration in "natural or simulated (artificial) icing conditions". This could perhaps be an icing wind tunnel.

AFFTC is actively improving its capability for icing test at this time and has an NKC-135 tanker modified to simulate icing conditions by providing artificial rain for icing tests at high speeds and a C-130 Palletized Airborne Water Spray System for artificial rain and icing tests at lower speeds. Both of these systems can produce icing conditions ober limited areas of the test aircraft such as radomes, windshields, engine air inlets (legally an engine test problem!) or ram air inlets to the air conditioning system. Thus we do have a capability for flight test if the individual case requires it.

ENVIRONMENTAL PROTECTION OF TRANSPARENT AREAS

Requirements for environmental protection of transparent areas have been summarized as follows:

Anti icing	Tables A8A (performance) and A8B (design)
Defrost/defog (internal surfaces)	Table A9A (performance) and 9B (design)
Rain and snow	Table A10
Insects, salt, dust	Table A11

There is, as one would expect, a great deal of commonality in the requirements in the areas to be protected and the design flight conditions. However, minor differences in these and differences in acceptable methods of protection make it desirable to tabulate each case separately. A comparative summary is shown in Table A12 (page 120).

In general, all "mission essential" transparent areas are to be protected (except for the "excessive rain" case). Defrost/defog and protection against rain and snow are specifically required in ground operations. Salt and insect protection are only called for when the mission calls for low level operation.

The protection mechanisms vary with the function and between aircraft but are commonly external hot air jet (anti-ice, rain, snow) internal hot air (defrost/defog) and washing (dust, salt, insects). Tests of anti-icing and rain removal can be performed using the AFFTC water spray tankers. Defrost and defog testing does not require external equipment and can be evaluated by rapid descent after cold soak and on climbs out of atmosphere with high water content or descents into humid conditions. Finding suitable conditions for these tests can be a problem unless the aircraft is deployed to a suitable test site. Not many Air Force aircraft have windshield washing equipment but if it is provided it should be evaluated.

Problem areas encountered are usually as follows:

a. area cleared of ice and rain inadequate - especially on fighter class aircraft with large areas requiring clearance

b. inadequate defogging and de-icing

c. high cockpit temperatures during defogging or de-icing.

OXYGEN SUPPLY

Oxygen may be supplied from a liquid oxygen converter (MIL-D-19326F) or gas cylinders (MIL-D-8683B). Passenger supply may be from chemical oxygen generators with the approval of the procuring agency. Crew supply is by demand regulators while passenger supply is to use an automatic, continuous flow regulator system. "Therapeutic" oxygen supply may be required in some aircraft (medical type).

Oxygen systems use standard tested components (converters, gas cylinders, regulators, masks and so on). As a result, evaluation of the system is limited to ride-along functional checks and evaluation of maintainability and serviceability and of the location of controls and indicators. Evaluation of the oxygen systems is primarily the responsibility of the Human Factors engineer. Paragraph 3.7.4 of MIL-D-8683B ,reference 10, (which is aimed primarily at the contractor) states:

"3.7.4 Flight test. When specified, flight tests on the oxygen systems shall be conducted to determine the proper functioning of all the oxygen equipment in the aircraft by actual crew use and/or functional measurements. In addition, a determination may be made of the suitability of the arrangement of the items from the standpoint of accessibility and convenience to all crew members during their flight duties".

Requirements of concern in flight test evaluation are summarized in Table A13 (page 121). Appropriate flight tests are discussed in the next section (Flight Test Planning).

PLANNING OF FLIGHT TESTS

This Section addresses planning of the content of ECS flight test program (including ground tests). The administrative procedures required to execute these plans are common to all AFFTC flight tests and will change from time to time. The engineer should be familiar with AFFTC Regulation 80-12 (Test Plan) and AFFTC Regulation 80-13 (Test Plan Technical Review) and related documents. Procedures for all-weather testing, an important part of ECS testing, are reviewed in reference 13. An example of a Test Information Sheet (TIS) for an ECS evaluation is given in Appendix B.

BACKGROUND OF TEST PROGRAM

The function of the ECS is to enable operation of the aircraft over the full range of operational environments it will encounter, on the ground and in the air (cold, heat, high absolute humidity, heavy rain, icing and so on). Although there are a number of ECS-peculiar tests, much of the data will be gathered on a ride along basis or, for example, during all-weather testing of the total system. ECS test requirements will, therefore, be integrated into a total flight test program designed to evaluate the weapon system as a whole.

ECS tests will usually be conducted in the context of Combined Test Force (CTF) operations and will consist of a coordinated, combined program. This program should be designed to meet the needs of all interested parties - primarily the contractor, Systems Program Office (SPO) and the AFFTC. The AFFTC flight test engineer conducts tests or participates in test conduct as necessary to ensure that AFFTC responsibilities are met. As the flight program and development of the test aircraft progresses the relative roles and responsibilities of the member of the test team will change. Initially, emphasis is on development testing. At this time the contractor has a lead role while the AFFTC engineer participates and conducts his own analysis and evaluations. Later, emphasis shifts to test and evaluation, with increased participation by AFTEC and using commands. The AFFTC engineer then assumes a lead role. Even though much of the work may be performed by the contractors team, he must initiate and conduct tests as necessary and oversee analysis and evaluation of results. This engineer should also establish good communications with flight and ground crews and ensure alertness to all ECS incidents relevant to evaluation.

The flight test engineer must become thoroughly familiar with the system both as described in Flight and Maintenance Manuals and as it exists in hardware form. These versions may differ significantly in the development phase of a new aircrqft (and sometimes in later phases). Simulation of the air conditioning/pressurization elements of the ECS, using a program such as 'EASY', is a very effective way of ensuring familiarity with this, the most complex and potentially troublesome part of the ECS (reference 12).

Careful record keeping is important. The engineer should make and adhere to specific plans to maintain detailed, accessible and complete test records for his own protection and for the benefit of his successor in case he does not complete the program and for use on future programs.

Information sources to be reviewed, and referenced in Test Information Sheets and reports, include the following:

Test Aircraft Flight Manual ("dash 1"), and/or Crew

Checklists

Aircraft Contract End Items Specifications

Military Specifications pertaining to the individual system or test (of appropriate dates)

Organization Maintenance Manuals ("dash 2")

Field Maintenance Manuals

Contractor System Operation and Service Manuals

Related AFFTC Reports

Formally published Contractor Test Plans

Formally published Contractor Test Reports

Program office requests (letters, TWX's, etc.)

Related test plans includes those of other participating commands

Hazard Analysis Safety Reviews (AFFTC Form 28) for similar test programs

CHARACTER OF ECS TESTS

The objective of an ECS test program is to ensure that the ECS adequately and effectively supports operation of the aircraft over the full range of flight and weather environments called for by its mission. Typically tests will include:

1. routine operations over the flight regimes called for by the mission, including operation with partial failure

2. normal ground servicing

3. stressing flight profiles

4. all-weather tests

The ECS provides a quite wide range of functions, ranging from tank pressurization to air conditioning. Many of these functions are stressed by the same flight profiles. Also, if instrumentation permits, useful evaluations of functioning of many components can be acquired during ride-along observations with other tests. This is particularly true, for example, of oxygen systems and anti-g suits. Table 2 (page 63) gives a fairly comprehensive list of test conditions and shows which components are stressed by them. This table illustrates the need for an integrated test program. A frequent source of problems is incompatability of the aircraft with the support equipment. This must be evaluated by performing normal checkout, post-flight and maintenance using the equipment called for in the Technical Orders.

All Weather Testing:

Procedures for these tests are described in Reference 13. These programs normally include tests in the McKinley Climatic Laboratory at Eglin AFB and field test at sites such as Alaska (winter), El Centro NAS (desert summer) and in the Canal Zone (tropical). Weather requirements are given in MIL-STD-210B. (reference 14) Essentially full operational capability is required under extreme operational conditions, although some special procedures may be acceptable for an otherwise satisfactory system. All weather tests of the ECS will be integrated by the all weather test engineer into a combined program testing the whole weapon system, using the Test Information Sheet (TIS) prepared by the ECS test engineer. This program will be subject to tight schedule constraints imposed by weather windows (Figure 19, page 64) and by availability of the Climatic Laboratory. Usually the ECS test engineer will accompany the test team during these deployments. Because of the schedule constraints it is necessary to obtain the maximum amount of data in the shortest possible time. This requires a significant amount of preplanning, a viable instrumentation system, including a quicklook playback system at the test site, and adequate manning.

The full range of ECS tests is not repeated, but normal operational profiles and maintenance must be demonstrated in the extreme weather conditions. Emphasis will be given to the more stressing profiles and also to any components of the ECS suspected to have marginal performance. Examples of stressing profiles are given below for each part of the ECS. Compatability will support equipment should be given careful attention.

TEST REQUIREMENTS FOR ECS COMPONENTS

Bleed Air System:

Test Objectives.

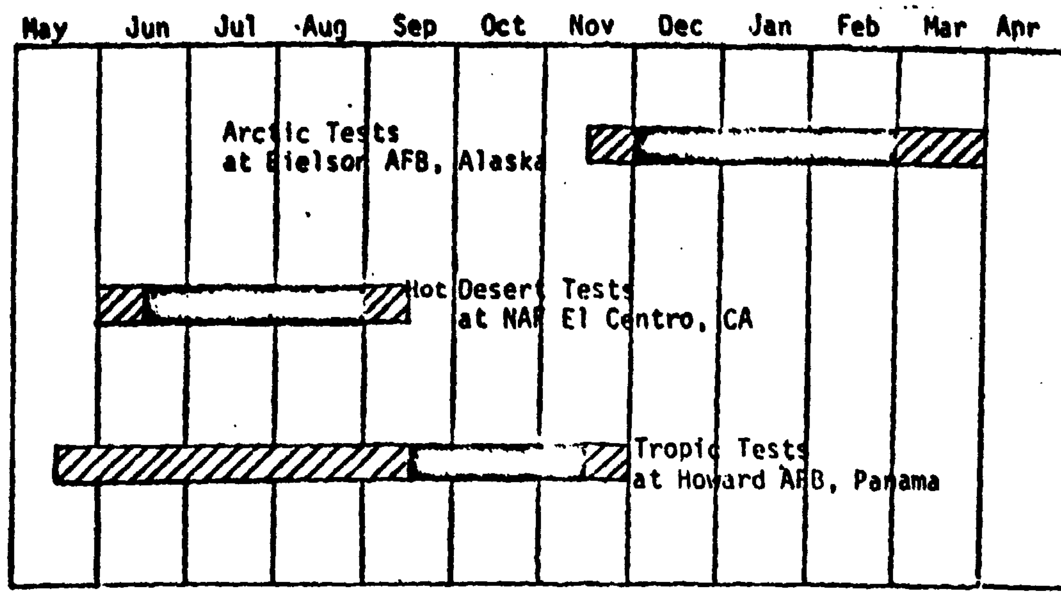
The test objectives are to determine if the bleed air system meets the requirements summarized in Tables A1A and A1B (pages 91 and 92). The primary requirements which influence flight test planning are:

Table 2 Relation of Flight Profiles to Component Tests

Flight Profiles And Conditions	Bleed Air	Pressurize Occupied	Pressurize Eqpt.	Pressurize Reservoir. Seals. Suits	Air Cond., Occupied	Air Cond., Eqpt.	Anti-Icing Non-Transp.	Anti-Icing Transp.	Defrost Defog	Rain & Snow	Insects, Salt, Dust	Oxygen
						Components Tested						
Complete Mission Profiles Ground Check to Post-Flight	X	X	X	X	X	X						X
Streaming Profiles												
Fast Climb		X	X	X	X	X						X
Max. Range Cruise (High)	X	X	X	X	X	High Load						X
Fast Descent After Cold Soak	X	X	X	X	X	X		X	X			
High Speed Dash (if Appropriate to Mission)					X	X						
All-Weather Tests												
Normal Mission Profile, Ground Check to Post-Flight	X	X	X	X	X	X						
High Speed Low Altitude After Cold Soak					X	High Load					X	
Low Speed Low Altitude After Hot Soak	X				X	High Load					X	
Low Altitude After Cold Soak	X				X	X						
Fast Climb From High Ground Level Water Content	X	X	X	X	X	X						
Descent from Cold Soak and Park in High Water Content	X	X	X	X	X	X		X	X			
Flight in Heavy Rain										X		
Flight in Dust/Salt											X	
Miscellaneous												
High G Maneuvers				X		(1)						
Compartment Pressure Dump		X	X									X
Artifical Icing								X				
Engine Transients		X	X	X	X	(2)	If Required					

(1.) Maybe required on new type of ACM etc.

(2.) If the air conditioning uses separate inlets.



Notes:

1. Conditions required for test are as follows:

   Arctic -20 deg F and below
   Hot Desert: 110 deg F and above
   Tropic: 80 deg F, RH 75 percent and above

2. Shaded areas denote prime test time, cross-hatched areas denote marginal test time.

Figure 19 Climatic Extremes Windows

1. the system shall provide air to all components requiring bleed air at the specified pressures, temperatures and mass flows

2. the system shall be able to supply the necessary quantities to all equipment requiring operation simultaneously

Test Conditions and Procedures.

The pressures, temperatures and mass flows to the components using bleed air will be monitored for all mission profiles. In particular, it will be evaluated during the following (Table 2, page 63).

1. long range cruise at high equipment cooling load (low engine powers)

2. fast descent at idle rpm (pressurization of compartments and reservoirs)

3. throttle transients (possible flunctuation in pressure)

Data and Support Requirements.

The following data are required:

1. Flight conditions

2. Engine settings

3. Pressures, temperatures and mass flows at each component

4. Pressure, temperature and mass flow from each engine/APU

Pressurization of Occupied Compartments:

Test Objectives.

The test objectives are to determine whether the system meets the requirements summarized in Tables A2A and A2B (pages 93 and 95). The main requirements which impact flight test planning are:

1. Maintenance of pressure altitude schedule in climbs, descents, etc.

2. Response to changes in setting (manual controls)

3. Freedom from contamination

4. Proper functioning of normal and emergency pressure release systems

5. Flow sufficient to meet ventilation requirements and in relation to uncontrolled in-service air leaks

Test Conditions and Procedures.

Flow rates and compartment pressures will be observed during the flight profiles shown in Table 2 (page 63). Specific tests will include observations of:

1. Maintenance of pressure altitude schedules

2. Response to changes in setting (when appropriate)

3. Leak rate (with pressurization off) during high altitude cruise (Appendix D)

4. Contamination measurement

5. On multi-engined aircraft, operation with one bleed air source off

6. Exercise of normal and emergency pressure dump

7. Throttle transients

Data and Support Requirements.

1. Time histories will be required as appropriate of

   a. flight conditions

   b. engine settings

   c. pressures in occupied compartments

   d. pressurization air flows

2. Contamination measurements will be required

3. Computerized data reduction will be required

Pressurization of Equipment Compartments:

Test Objectives.

The test objectives are to evaluate:

1. whether the equipment pressurization meets specified requirements and

2. over and above (1), whether the equipment pressurization system satisfactorily supports the mission.

General requirements are summarized in Table A3 (page 97). Details of the requirements are, however, peculiar to the aircraft system under test and must be derived from the aircraft and item specifications and the appropriate equipment specifications, which the ECS flight test engineer must review. Compartment pressures of compartments which are separate from occupied compartments are to be regulated automatically.

Test Conditions and Procedures.

Test conditions and flight profiles are summarized in Table 2 (page 63). The tests closely parallel the tests of air conditioning of equipment compartments, discussed a little later, and will be part of the same sets of measurements.

Tests will consist of the observation of pressures in all equipment compartments throughout the mission flight regime. Stressing cases are primarily climb, fast descent with engines at idle, long range high altitude cruise, and possibly (on fighters) engine transients.

Data and Support Requirements.

These are:

1. Recording of data
    a. compartment pressures
    b. flight conditions
    c. engine settings
2. Computerized reduction of data

Pressurization of Subsystem Reservoirs, Inflatable Seals and Suits:

Test Objectives.

The test objectives are to determine if the pressurization system supplies pressurized air at specified pressures, temperatures, moisture and contamination levels to all subsystem reservoirs such as fuel tanks, oil, hydraulic fluid, coolant or water reservoirs and to pressure suits or anti-g suits if relevant. In the case of suits, proper functioning of the suits will also be checked.

Test Conditions and Procedures.

Pressures, temperatures, and where appropriate moisture and contamination levels will be recorded throughout the flight

profiles summarized in Table 2 (page 63). Stressing conditions are fast climb, fast descent at low power, and long range cruise or loiter at high altitude. For pressure suits, operation should be checked during cabin depressurization. For anti-g suits, operation will be checked in appropriate combat maneuvers.

Data and Support Requirements.

These are:

1. Recording of

   a. pressures, temperatures, moisture and contamination

   b. flight conditions

   c. engine settings

   d. crew comments on suit operation

2. Computerized reduction of data

Air Conditioning of Occupied Compartments:

Test Objectives.

The purpose of cabin air conditioning tests is to evaluate if the system meets following requirements:

1. Ventilation rates are to be at least 20 cubic feet per minute (cfm) per man for all operating conditions and at least 1.8 times the maximum allowable production leakage rate for all pressurized operations. Air velocities near seated personnel are not to exceed 300 feet per minute (fpm).

2. Radiating surfaces are to be at least 50 degrees F and are not to exceed 105 degrees F near seated personnel during pressurized flight, and are not to exceed 140 degrees F for all other locations and conditions.

3. Air supplied to the occupied compartments is to be free of entrained moisture.

4. Air supplied to the occupied compartments is to be free of excessive contamination.

5. The automatic temperature control is to maintain the average compartment air temperature to within ± 3 degrees F of selected settings. Temperature variations between any two points in a seating envelope are not to deviate more than ± 5 degrees F from the average cabin temperature.

Temperature differences outside the envelope are not to vary more than $\pm$ 10 degrees F from the average cabin temperature.

6. Floor temperatures are to be maintained above 60 degrees F average, with no location less than 40 degrees F.

7. Average cabin temperatures are to be maintained between 45 degrees F and 90 degrees F for unpressurized flight and between 70 degrees F and 90 degrees F during flights with an inoperative air conditioning unit (multiple unit system).

8. The air-conditioning equipment, operating from either aircraft engines or from the APU, is to be capable of preventing the average compartment temperature from exceeding 100 degrees F.

9. The heating equipment is to be capable of maintaining the average compartment air temperature above 80 degrees F.

10. The conditioning system is to be compatable with the support equipment called for in the Technical Orders.

Test Conditions and Procedures.

Air conditioning of occupied compartments is very important throughout the whole mission profile from ground check out to post flight. Test conditions and flight profiles of primary concern are summzrized in Table 2 (page 63). Stressing conditions include:

1. Fast climb and fast descent
2. Extended cruise or loiter at high altitude
3. Low altitude flight after hot soak and cold soak
4. Conditions with high atmospheric water content
5. Supersonic cruise (when applicable)
6. Low altitude supersonic dash
7. Ground checkout, post-flight, and maintenance

Much useful data on compartment temperature and airflow distribution shortcomings can be acquired during normal flight profiles but this system must be fully checked during all-weather testing.

Tests must include evaluation of air conditioning with one air conditioning unit, one "failed" on multiple unit systems and tests using emergency ram air.

If the aircraft is equipped with guns, contamination levels in the cockpit should be checked during gun firing throughout the gun firing envelope. For these tests the crew should be on 100% oxygen until cockpit contamination levels are determined and found to be safe.

<u>Data and Support Requirements</u>.

These include the following:

1. Recording of:

   a. ventilation rates (compartment air inlet temperature and flow rate)

   b. air velocities at crew positions

   c. temperature distributions at crew positions

   d. temperatures of floors and radiating surfaces

   e. contamination and noise levels

   f. flight conditions

   g. engine settings

   h. air conditioning system configuration

   i. crew comments on system controls and operation

2. Computer reduction of data

3. Ground support equipment as called for by Technical Orders.

<u>Equipment Conditioning</u>:

Equipment conditioning is very important for ground check out and servicing as well as throughout the operational flight regime, and will require a substantial part of the ECS testing effort.

<u>Test Objectives</u>.

The test objectives are to evaluate:

1. how well the equipment conditioning meets the requirements imposed by the aircraft end item specifications and equipment specifications.

2. whether the equipment conditioning system satisfactorily supports the mission.

Test Conditions and Procedures.

Test conditions are summarized in Table 2 (page 63), and may include:

1. Extended cruise or loiter at high altitude (low available bleed air flow)

2. Supersonic cruise (when applicable)

3. Descent at idle power

4. Operation with an ACM failed and cooling using ram air

5. Low altitude flight after hot soak on ground (at low power and supersonic dash)

6. Low altitude flight after cold soak on ground

7. Landing in conditions with high water content after cold soak at high altitude

8. Ground servicing

The system must be fully checked during all-weather testing.

Data and Support Requirements.

These include:

1. Measurements of temperature, pressure, flow, moisture and contamination level of air supplied to air cooled equipment and equipment compartments.

2. Measurement of coolant temperature, flow and flow conditions through the heat exchangers for liquid cooled equipment.

3. Check for water and potential fungus problems

4. Crew comments

5. Computerized data processing

6. Support equipment called for in the relevant Technical Orders.

Anti-Icing of Non-Transparent Areas:

As was explained in the preceding Section on Requirements and Problem Areas, full anti-icing of flight surfaces is very rarely called for on Air Force aircraft. Anti-icing over limited areas such as radomes and ECS air scoops is more likely to be required. If flight evaluation of such anti-icing is required tests can be made using artificial icing from one of the AFFTC tanker water spray systems.

If anti-icing is provided the relevant flight conditions will be defined in the aircraft end item specifications and/or the ECS specification.

Test Objectives.

The test objectives are to evalute the ability of the anti-ice system to maintain satisfactory operation of specified components under the flight conditions defined in the requirements, with meteorological conditions defined in Figure A1 (page 123).

Test Conditions and Procedures.

The test aircraft is positioned behind the water spray tanker at a distance predicted to give the desired liquid water content in the spray. Sea marker dye may be used to determine the type of ice formed exactly when the ice starts to melt. Additional information on test prodecures can be found in Reference 15. Photographic records of the ice build up are taken, using a photo chase aircraft if necessary.

Data and Support Requirements.

The following are required:

1. The NKC-135 or C-130 palletized water spray system

2. A record of flight conditions, including ambient air temperature, separation distances and liquid water contents

3. Component performance parameters (including temperatures of anti-icing air/fluid, surface temperatures, electrical power where applicable)

4. Photo records, if necessary from a photo chase aircraft

5. Engineering chase to accomodate the engineering test conductor

Anti-Icing of Transparent Areas:

Windshields, bombardiers panels and all other mission essential areas are to have anti-icing protection for all conditions of flight (Table A8A, page 114). If there is a risk of overheating, temperature limiting devices must be installed.

Test Objectives.

The test objectives are to evaluate the ability of anti-ice system to protect all mission essential areas in all conditions of flight for meteorological conditions summarized in Figure A2 (page 124).

Test Conditions and Procedures.

These tests will also be made using the AFFTC NKC-135 or C-130 palletized airborne water spray system. The test aircraft is positioned behind the water spray tanker at a distance predicted to give the desired liquid water content in the spray. Sea marker dye may be used to determine exactly when the ice starts to melt. Photographic records of the ice build up will be taken. Additional information on test procedures can be found in reference 15.

Data and Support Requirements.

The following are required:

1. The NKC-135 or C-130 palletized airborne water spray system

2. A record of flight conditions including ambient air temperature, separation distances and liquid water content

3. Component performance parameters (including temperature of anit-icing air, surface temperatures and electrical power if applicable)

4. Crew comments

5. Photo records from a photo chase aircraft

6. Engineering chase aircraft to accomodate the engineering test conductor

Defrosting and Defogging of Transparent Areas:

Defrosting and defogging is required for windshields, bombardiers panels and all other mission essential areas for all flight conditions and in taxiing. Areas to be protected include those needed for taxiing. Performance and design requirements are summarized in Tables A9A and A9B (pages 116 and 117) respectively.

Test Objectives.

These are to evaluate the ability of the defrost/defog system to protect all mission essential transparent areas during taxing and under all flight conditions.

Test Conditions and Procedures.

The ability of the defrost/defog system to protect mission essential transparent surfaces will be evaluated during and after descents from cold soak at high altitude as follows:

1. During descent at recommended descent speed

2. In low altitude level flight after (1)

3. For combat aircraft, during maximum rate of descent at limit speed

4. In low altitude level flight after (2) (3) Tests (1) and (2) will be repeated during tropical tests and also with one air conditioning unit inoperative on multi-unit systems.

Data and Support Requirements.

The following data are to be recorded:

1. Flight conditions and flight profile

2. ECS operating configuration

3. Defog air temperature and mass flow (if hot air jets used)

4. Surface temperatures

5. Meteorological conditions, cockpit temperature and cockpit humidity

6. Crew comments

7. A photo record of frost/fog build up

Crew comments should include any adverse impact of operation of the defrost/defog system on crew comfort.

Removal of Rain and Snow from Transparent Areas:

Pilot and copilot windshields are to be protected. Also, sensor windows are to be protected for all inflight conditions for which sensor operation is required. Flight conditions are summarized in Table A10 (page 118).

Test Objectives.

To evaluate the protection of transparent areas against heavy rain, and excessive rain and snow. Also, to check for the possibility of erosion by the rain.

Test Conditions and Procedures.

Flight tests will be made using one of the AFFTC spray tankers and also when suitable weather is available. They will include as feasible:

1. Taxi, take off, landing approach and landing

2. Flight at 1.6 times the stall speed at maximum weight with gear and flaps up, for fixed wing aircraft

3. Flight at maximum cruise speed for rotary wind aircraft

4. In flight refueling conditions, if refueling is required below 20,000 ft.

Simulation tests may also be conducted in the Climatic Laboratory. Details on procedures using the AFFTC spray tanker to provide simulated rain will be found in reference 15.

Data and Support Requirements.

The following data are required:

1. Flight conditions

2. Weather conditions

3. Jet air temperature and mass flow (if air jets used)

4. Surface temperatures in the impingement area

5. Crew comment on protection

6. If feasible, photographic records of clearance

Protection Against Dust, Salt Spray or Insects:

Protection is required for pilot and copilots windshields and for sensor windows on aircraft whose mission requires low level flight over the oceans or along the coast (salt) or overland (dust and insects). Vertical take off and landing aircraft are to have protection for the pilot and copilots windshields (Table A11, page 119).

Test Objectives.

To evaluate the protection provided.

Test Conditions and Procedures.

Fixed wing aircraft will be flown low over land or water as appropriate in the manner called for in its mission profile at times when weather/sea conditions are suitable for evaluation.

Rotary wing aircraft will be operated under dusty conditions as opportunity permits.

Data and Support Requirements.

The following data will be recorded:

1. Flight conditions, including height above ground/water
2. Weather/sea conditions
3. Flight and ground crew comments

Oxygen Systems:

Test Objectives.

Oxygen systems are primarily evaluated during normal ground servicing and flight missions. Evaluation is for proper functioning, suitability of arrangement, accessibility and convenience.

Test Conditions and Procedures.

Crew comments are obtained during normal flight profiles and ground servicing. In addition, proper functioning is checked during compartment pressure dump tests and cabin leakage tests.

Data and Support Requirements.

Crew comments are required on system functioning and on the suitability of the arrangement of the items from the standpoint of accessibility and convenience to all crew members during their flight duties and during servicing.

General requirements for instrumentation for contractor flight tests of ECS are given in MIL-E-38453A, paragraph 4.10. Requirements for AFFTC tests are essentially similar. In summary, these must measure:

a. temperature, pressure, flow and sometimes moisture content of air delivered by the bleed air system to all components

b. temperatures and velocities around crew stations

c. temperatures, pressures and flows in and out of heat exchangers

d. data in sufficient quantities to provide a thorough analysis of the environmental control system performance

Generous use of temperature indicating stickers is very helpful, especially on equipment.

The engineer should review pickup locations and should review all calibrations to ensure that they cover the appropriate ranges, do not exhibit excessive hysterisis, show adequate accuracy and are in general acceptable. ± 3% of range is generally acceptable, but ± 1% is desirable in all-weather tests. Often ECS testing is performed on more than one aircraft, in which case the parameter selection may differ between these in order to reduce total band width requirements. Table 3 (page 79) gives an example of an instrumentation parameter list for a single place fighter (F-16). A large cabin aircraft such as the E-3A would, of course, need many more measurements in the occupied compartments.

On an all-weather test aircraft the ECS must compete with other subsystems for instrumentation capacity (Ref 13). Hence, ECS instrumentation will tend to concentrate on output performance parameters (cabin temperatures and so on) rather than on the inner working of, for example, the air conditioning units. Some key diagnostic parameters should, however, be included.

The overall objective of ECS tests is to evaluate the ECS as a subsystem of an operational aircraft and to determine if any serious problems or deficiencies exist. This evaluation will draw on qualitative comments of air and ground crews and on experience gained in tests flown for other objectives and/or on other test aircraft of the type as well as on data from tests specifically made to evaluate the system.

The final report on the evaluation will give a brief description of the system and draw attention to leading particulars and to the basic logic of its operation. For each test the aircraft

model, designation and serial number will be given. The general approach will be to discuss each component or function in turn, briefly list the relevant evaluation criteria and state whether these were met. Indicate briefly overall results and trends. The criteria must always include the overriding criterion of operational suitability as well as that of meeting specification requirements. If the subsystem fails to meet a specification requirement it may still be considered operationally acceptable. Further, it may meet specification requirements and still be considered unsuitable for operational use.

When criteria are not met enough detail must be given to effectively define the short-fall. Tabular summaries or time histories will be given of the tests conducted with appropriate comment. Where appropriate, as in dynamic conditions in general, time history plots will be presented with attention drawn to the important parameters. In some cases cross-plotting will be very helpful. Still photographs are an important and highly effective means of illustrating some types of problem. The engineer should ensure that appropriate photographic documentation is obtained. Photographs of pools of water in the cabin or of an iced over windshield can be quite convincing.

Objectives, pertinent parameters, criteria and presentation recommendations for analysis, evaluation and reporting of tests of each compartment are collected, for ease of reference, in Appendix C.

Table 3

EXAMPLE OF ECS INSTRUMENTATION PARAMETER LIST

PARAMETER CODE No.	DESCRIPTION	RANGE	SAMPLE RATE (SAMPLES/SEC)
AD004	FCS Normal Accel	−9 to 13g	50
DA007	Pilot's Operated Event Marker (TO THG IN POD)	—	12.5
DD024	Cockpit Temp Cont SW Position (MANUAL)	0 to 10 vdc	3.125
DD025	Cockpit Temp Cont SW Position (AUTO)	0 to 20 vdc	3.125
DD026	Equip Cooling Flow Cont Valve Position	0 to 30 vdc	12.5
DP014	Power Lever Angle	180°	6.25
FD015	RPM, N_2 (PROD)	1500 rpm	12.5
FD016	Cooling Turbine rpm	30K to 100K rpm	25
HE008	Event, 15 vdc	DISCRETE	50
HE010	Event, +5 vdc	DISCRETE	50
HE023	Event, ATIS +28 vdc EXC	DISCRETE	50
MB001	Cockpit Humidity	0 to 100%	3.125
MB002	Cockpit Tot Rad Heat Load	443 Btu/ft^2/hr	3.125
FB002	F-1 Bladder Press	0 to 30 psia	6.25
FB033	F-1 Tank Cavity Press	0 to 30 psia	6.25
FD010	Calibrated Airspeed	0 to 1028kt	50
FD011	Press Altitude	0 to 80Kft	50

Table 3 (continued)

PARAMETER CODE No.	DESCRIPTION	RANGE	SAMPLE RATE (SAMPLES/SEC)
FD012	Press ALT (SYNCHRO)	0 to 10 ft	50
PF001	Cabin AMB Press	0 to 20 psia	12.5
PY019	EPU Bleed Air Supply Line Press	0 to 150 psia	3.125
PY031	ECS Turb Inlet Press	0 to 150 psia	12.5
PY032	ECS Turb Outlet Pres	0 to 20 psia	12.5
PY128	Supply Duct Total Press	0 to 20 psia	12.5
PY130	Supply Duct Static Press (PY033-PY034)	±15 psid	12.5
PY035	Defog Divert Valve Press	0 to 10 psid	3.125
PY069	Flow Lim Vent Inlet Ps Upstm of Cool Cont Valve	0 to 20 psia	12.5
PY071	Flow Lim Vent Inlet To Throat Ps (PY069-PY070)	0 to 5 psid	12.5
PY076	FWD Equip Bay Duct Total	0 to 20 psia	3.125
PY078	FWD Equip Bay Duct P (PY076-PY077)	0 to 5 psid	3.125
PY079	AFT Equip Bay Duct Total Press	0 to 20 psid	3.125
PY081	AFT Equip Bay Duct P (PY079-PY080)	0 to 5 psid	3.125
PY125	Bleed Vent Exit Total Press	0 to 100 psid	12.5

Table 3 (continued)

PARAMETER CODE No.	TEST ITEM	RANGE	SAMPLE RATE SAMPLES/SEC
PY127	Bleed Vent Exit Tot vs Depress Static (PY125-126	+25 psid	12.5
PY105	IMU Takeoff Duct Total Press	0 to 20 psid	3.125
PY113	Under FLR Bay Duct Ps @ Cooling Cont Sensor	0 to 5 psig	3.125
TB010	EPU Bay AMB Air Temp # 1	-70° to $900^{\circ}F$	6.25
TB012	RH Strake AMB Temp # 1	-70° to $190^{\circ}F$	3.125
TB013	RH Strake AMB Temp # 1	-70° to $190^{\circ}F$	3.125
TB021	EPU Bay AMB Air Temp # 2	-70° to $900^{\circ}F$	6.25
TB024	Nosewheel Wall AMB Temp	-70° to $190^{\circ}F$	3.125
TB025	Main Wheel Wall AMB Temp	-70° to $190^{\circ}F$	3.125
TB026	Vert Tail Root AMB Temp	-70° to $190^{\circ}F$	3.125
TD017	Total Temp Prod Probe (RAT)	-70° to $900^{\circ}F$	3.125
TF002	Cabin AMB Temp @ Head 1st STA	-70° to $190^{\circ}F$	3.125
TF004	Cabin AMB Temp @ Waist (L)	-70° to $190^{\circ}F$	3.125

Table 3 (continued)

PARAMETER CODE No.	DESCRIPTION	RANGE	SAMPLE RATE (SAMPLE/SEC)
TF005	Cabin AMB Temp @ Waist (R)	[illegible] to 190°F	3.125
TF003	Cabin Temp @ Foot	-70° to 190°F	3.125
TF013	Bud Surface Temp # 1	-70° to 500°F	3.125
TF014	Bud Surface Temp # 2	-70° to 500°F	3.125
TF015	Cockpit Compartment Surface Temp	-70° to 500°F	3.125
TY010	Cabin AMB Temp @ Sensor	-70° to 190°F	3.125
TY011	Cabin Console AMB Temp # 1	-70° to 190°F	3.125
TY012	Cabin Console AMB Temp # 2	-70° to 190°F	3.125
TY014	Cabin Console AMB Temp # 4	-70° to 190°F	3.125
TY017	Under Glare Shield AMB Temp # 1	-70° to 190°F	3.125
TY018	Under Glare Shield AMB Temp # 2	-70° to 190°F	3.125
TY019	Under Glare Shield AMB Temp # 3	-70° to 190°F	3.125
TY021	FWD Equip Bay AMB Temp # 1	-70° to 190°F	3.125
TY022	FWD Equip Bay AMB Temp # 2	-70° to 190°F	3.125

Table 3 (continued)

PARAMETER CODE No.	DESCRIPTION	RANGE	SAMPLE RATE (SAMPLE/SEC)
TY023	FWD Equip Bay AMB Temp # 3	-70° to 190°F	3.125
TY024	FWD Equip Bay AMB Temp # 4	-70° to 190°F	3.125
TY025	AFT Equip Bay AMB Temp # 1	-70° to 190°F	3.125
TY026	AFT Equip Bay AMB Temp # 2	-70° to 190°F	3.125
TY027	AFT Equip Bay AMB Temp # 3	-70° to 190°F	3.125
TY029	Lower Equip Bay AMB Temp # 1	-70° to 190°F	3.125
TY030	Lower Equip Bay AMB Temp # 2	-70° to 190°F	3.125
TY031	Lower Equip Bay AMB Temp # 3	-70° to 190°F	3.125
TY032	Lower Equip Bay AMB Temp # 4	-70° to 190°F	3.125
TY033	Lower Equip Bay AMB Temp # 5	-70° to 190°F	3.125
TY034	Lower Equip Bay AMB Temp # 6	-70° to 190°F	3.125
TY035	Under Floor Bay AMB Temp # 1	-70° to 190°F	3.125
TY038	Under Floor Bay AMB Temp # 4	-70° to 190°F	3.125
TY039	Avionic Cooling Control Valve Inlet Temp	-70° to 380°F	3.125

Table 3 (continued)

PARAMETER CODE No.	DESCRIPTION	RANGE	SAMPLE RATE (SAMPLE/SEC)
TY040	Supply Sir Temp	-70° to 380°F	12.5
TY041	Warm Airline Temp	-70° to 380°F	12.5
TY042	Cooling Turbine Inlet	-70° to 190°F	12.5
TY043	Venturi Inlet Air Temp	-70° to 1400°F	12.5
TY052	Regenerative HX Hot Side Temp	-70° to 900°F	12.5
TY053	Cabin Exit Air Temp @ Press Regulator Inlet	-70° to 190°F	3.125
TY067	FWD Equip Bay Duct Air Temp	-70° to 190°F	3.125
TY068	AFT Equip Bay Duct Air Temp	-70° to 190°F	3.125
ME001	Anemometer	0 to 1000 ft/min	12.5
ME002	Free Air Temperature	-40° to 40°C	12.5
ME003	Dew Point	-40° to 50°C	12.5
ME004	Black Globe	-40° to 40°C	12.5
ME005	Cabin Pressure	0 to 800 mm Hg	12.5
ME006	Cabin Temperature	-40° to 40°C	12.5
ME007	Cabin Temperature	-40° to 40°C	6.25
ME008	Cabin Temperature	-40° to 40°C	6.25
ME009	Cabin Temperature	-40° to 40°C	6.25
ME010	Cabin Temperature	-40° to 40°C	6.25

Table 3 (concluded)

PARAMETER CODE No.	TEST ITEM	RANGE	SAMPLE RATE SAMPLES/SEC
TY043	Venturi Inlet Air Temp	-70 to 1100 °F	10
TY052	Regen HX Inlet Temp Hot Side	-70 to 300 °F	10
TY053	Cabin Exit Air Temp (Press Reg In)	-70 to 200 °F	10
TY057	ECS Compressor Inlet Air Temp	-40 to 900 °F	10
TY058	ECS Compressor Outlet Air Temp	-40 to 900 °F	10
TY059	PRI/SEC HX Exit Temp # 1		10
TY060	PRI/SEC HX Exit Temp # 2		10

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13. All-Weather Testing, AFFTC Systems Engineering Branch Handbook, Vol II, Chapter V, Part I, Clendon L. Hendrickson, January 1981.
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APPENDIX A

SUMMARY OF SPECIFICATION REQUIREMENTS FOR ENVIRONMENTAL CONTROL SUBSYSTEMS

Note: The test engineer should review the specifications applicable to the specific aircraft he is concerned with. These will usually be the versions current at the time when the aircraft is designed.

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Table A1A

Engine Bleed Air System

Performance Requirements

The system shall provide air to all components requiring bleed air at the specified pressures, temperatures and weight flows. (3.1.3.1)

Leakage at any one joint shall not exceed 0.01 cubic feet per minute per inch of duct diameter. Total leakage is to be kept to a minimum. (3.1.3.1).

If duct failure results in an open line, bleed air shall not be extracted from the engine(s) at a rate greater than the engine manufacturers limit. (3.1.3.1).

The system shall be able to supply the necessary quantities to all equipment requiring operation simultaneously. (3.1.3.1).

A normally open shut-off valve, which fails in the open position, shall be provided at each source of bleed air. (Manifold bleed parts on a single engine are considered to be a single source). (3.1.3.5).

Note: Paragraph references are to Reference 5, (MIL-E-38453A).

Table A1B

Engine Bleed Air System

Design Requirements

Each subsystem deriving air from the engine bleed air shall have an individual shut-off valve so that the subsystem can be deactivated without deactivating the engine bleed air system. (3.2.4).

All parts of the engine bleed air system shall be designed to withstand the simultaneous application of the most critical combination of pressure, temperature and motion encountered in operation. (3.2.4).

Internal velocities shall not result in a Mach number exceeding 0.25. (3.2.4).

There shall be no aerodynamic resonances. (3.2.4).

Sufficient, accessible joints shall be provided to facilitate installation and replacement and shall be clamped with quick-detachable couplings designed to minimize leakage. Safety-latch-type couplings shall be used where the bleed air temperature normally exceeds 450°F. (3.2.4).

Shut-off and regulator valves shall be designed to preclude failure or malfunction due to freezing of extrained moisture or corrosion. (3.2.4.3).

Where multiple engine or multiple stage bleed will occur, a check valve to prevent reverse flow of air into the engine shall be provided near each engine bleed port. A check valve to prevent reverse flow of pressurizing air shall be provided in each supply line to a pressurized compartment. Check valves that are installed at duct joints should be attached to the downstream portion of the duct to maintain pressurization integrity if the joint separates. A shut-off valve for each independent source of bleed air shall be provided as near as possible to the source and remotely controlled from the crew station. The shut-off valve shall be normally open and shall fail open. Provisions shall be made to provide closure of the valve during engine starting. Where multiple sources are manifolded, isolation and crossover means shall be provided to isolate each main supply duct and crossfeed to subsystems from any source. Isolation valves shall be normally open and shall fail open. Crossover valves shall be normally closed and shall fail closed. A readily accessible means for manually opening the crossover valve shall be provided. Provisions to assure that a rupture in the crossover ducting will not result in loss of all compartment pressurization airflow shall be provided. The isolation shut-off valve in each side shall be upstream of any supply line takeoff for compartment cooling or pressurization. (3.2.4.3).

Note: Paragraph references are to Reference 5, (MIL-E-38453A).

Table A2A

Pressurization of Occupied Compartments

Performance and Functional Requirements

Applicability. Required for all crew members and passengers in aircraft with operating altitudes greater than 20,000 feet (3.1.1.1.1).

Operation. Shall require minimum attention and manipulation by pilot/crew members.

Schedule.

Cargo and personnel transports, navigation trainers and early warning aircraft: Cabin altitude selectable between -1000 and +10,000 feet subject to maximum differential pressure equivalent to the difference between 8000 feet cabin altitude and the maximum operating cruise altitude of the aircraft (3.1.1.1.1.1).

Other aircraft: Cabin unpressurised up to 8000 feet, then maintained at 8000 feet pressure altitude to the operational ceiling of the aircraft (maximum altitude at which the aircraft can sustain level flight). If mission operation above 40,000 feet lasts one hour or less, a minimum of 5 psi differential above 23,000 feet is acceptable if a substantial weight savings results (3.1.1.1.1.1).

Pressure Regulation. Pressure shall be within ± 0.4 inches Hg of nominal selected when the cabin is pressurized, within the range 0 to +1 inch Hg when the cabin is unpressurized. Overshoot shall be less than 1 psi and fluctuation frequency less than 0.15 cps when the setting is changed, less than 0.2 psi for transient changes when engine settings are changed (3.1.1.1.1.2).

Rate of Change. For cargo etc aircraft, the rate of change of cabin pressure altitude to be selectable between 100 and 2000 feet/min. For others, not to exceed 1 psi/sec decreasing or 0.5 psi/sec increasing (3.1.1.1.1.2).

Excess Differential Pressure. A separate outflow valve, safety valve or combination of valves shall be capable of passing the entire air input to the cabin at a pressure not in excess of 110 percent of the normal maximum operational differential pressure but shall not relieve at a pressure less than 0.15 psi about the upper tolerance limit of the maximum normal poperational differential pressure. Protection shall also be provided against excessive negative differential pressure (3.1.1.1.1.2).

Opening of Canopies, Doors, Hatches. Provision shall be made to ensure that detrimental residual differential pressure shall not exist when such items are opened (3.1.1.1.1.2).

Note: Paragraph references are to Reference 5, MIL-E-38453A.

Table A2A

Pressurization of Occupied Compartments

Performance and Functional Requirements - continued

Pressure Release. Normal and emergency pressure release shall be provided. Where possible these shall be additional functions of the safety valve. Normal pressure release shall be capable of dumping cabin pressure without shutting off the pressurization air source. Emergency pressure release is to be activated by a single control and shall shut off the pressurizing air source automatically. The time to accomplish pressure release after initiation of emergency release shall be as follows:

(a) an aircraft with emergency escape provisions for all occupants, reach a pressure within 1 psi of ambient at an average rate of 0.5 to 1.0 psi per second

(b) other aircraft, 60 seconds for cargo and personnel transports, navigation trainers and early warning aircraft, 15 seconds for others (3.1.1.1.1.3)

Available Flow. The pressure source, whether it is controlled air from the air conditioning system or stored gas or a combination of both, shall provide sufficient flow to overcome allowable uncontrolled in-service air leaks and maintain the required pressure schedule and shall provide the required ventilation rate. When pressurization is by stored gas supply the partial pressure of oxygen in the occupied compartment shall be equivalent to that at 8000 feet. (3.1.1.1.1.4)

Emergency Enclosed Systems. When these are installed a separate pressurization source shall be provided for use during the escape sequence and descent to earth and during periods of failure of the aircraft pressurization system. (3.1.1.1.1.4)

Note: Paragraph references are to Reference 5, MIL-E-38453A.

Table A2B

Pressurization of Occupied Compartments

Design Requirements

Pressurization Source. The air used for compartment conditioning, when available at compatible weight flows and pressures, shall be used for pressurization. During flight conditions when the conditioned air weight flows and pressures are marginal for providing pressurization a means to supplement pressurization airflow shall be provided. When compartment conditioning air is not suitable, first consideration should be given to using temperature controlled bleed air before using high pressure stored gas as the pressure source. (3.2.2.1.1.1)

Multiple Sources and Single Failures. On multi engined aircraft at least two sources shall be provided, capable of providing the required pressurization individually with a means of selecting each source, combinations of sources or the "off" position. No single failure of any supply or control component shall result in the occupied compartment pressure altitude exceeding 14,000 feet on multi engined, passenger carrying aircraft that do not fly above 50,000 feet. No single failure shall result in conditions where crew or passenger safety is jeopardized with the use of available oxygen provisions on aircraft flying in excess of 42,000 feet. No single failure shall result in the failure of any other component either directly or indirectly. (3.2.2.1.1.1)

Check Valves. Check valves or other suitable automatic means of sealing all pressurization supply inlet openings into pressurized compartments to prevent rapid loss of compartment pressure in the event of air source failure shall be provided. When two or more sources supply a compartment through common ducting a check valve or other suitable automatic device shall be included in the inlet line from each source. (3.2.2.1.1.1)

Regulators, Safety Valves and Blow out Panels. At least one pressure regulator shall be installed in each portion of the aircraft where occupied compartment pressure can be maintained independently or in each portion of an occupied compartment where segregation is possible. Pressure reglator outflow valves shall be designed so that they will remain in their last position or close in case of failure. Means of making the regulator inoperative in the closed position shall be incorporated to enable occupied compartment pressure and leakage tests to be conducted on the ground, with means to prevent leaving the valve in the closed position. Protection of occupied compartments from excessive positive or negative differential pressures shall be provided. Safety valves shall be designed so that they will remain in the last position or close in case of failure. Blow out panels or sufficient flow areas between compartments to prevent personnel injury and structural failure in the event of sudden decompression shall be provided. Regulators, safety valves

Note: Paragraph references are to Reference 5, MIL-E-38453A.

Table A2B

Pressurization of Occupied Compartments

Design Requirements - continued

or outflow portions of each shall be protected against damage or tampering. Discharge parts shall be located in an ambient pressure area not subject to exposure to adverse weather conditions such as icing or rain or to physical interference from structures, insulation or any other installed items. (3.2.2.1.1.2 and 3.2.2.1.1.3)

Single Failure. No single component failure, sensor or control line leak shall result in simultaneous failure of both the compartment pressure regulator and the safety valve. (3.2.2.1.1.3)

Instruments and Controls. A caution indicator to show loss of compartment pressure below 10 psia shall be provided in the crew station of all aircraft having occupied pressurized compartments, except for aircraft designed to a 5 psig schedule. A warning light to warn occupants that compartment pressure has dropped below 3 psia for combat aircraft and 8 psia for passenger carrying aircraft shall be provided in the crew stations of all combat aircraft that operate above 42,000 feet and passenger carrying aircraft that operate above 25,000 feet, respectively.

Crew station controls for accomplishing pressure release shall be provided. Crew stations controls for selecting cabin rate of climb and descent and variable isobaric altitude, cabin pressure altitude indicators, instruments to show cabin rate of climb and descent in feet per minute and cabin pressure differential in psi shall be provided in the crew compartment of cargo and personnel transports, navigational trainers and early warning aircraft. (3.2.2.1.1.2.3)

Note: Paragraph references are to Reference 5, MIL-E-38453A

Table A7

Equipment Pressurization

Unit Pressurization.

Equipment requiring individual unit pressurization from an external source shall be supplied flows at pressures, temperatures, humidity, and contamination levles that are compatible with the equipment specification and MIL-E-5400. When two or more units are pressurized by the same source, loss of pressurization by one shall not cause loss of pressurization to the other units. Pressure relief provisions to prevent overpressurization of the equipment shall be incorporated. When radar units are pressurized by individual pressurizing sets, the AN/ASQ-14, the AN/ASQ-15, or the AN/ASQ-70 pressurization set (government-furnished aeronautical equipment) shall be used wherever compatible with the radar pressurization requirements. (3.1.1.1.2)

A pressure regulator shall be provided when necessary to insure pressures compatible with the equipment. Provisions that allow ground checkout of the pressure regulator, relief provision, and system leakage shall be incorporated. Providing a means for indicating loss of equipment pressurization to the crewmembers shall be given consideration. (3.2.2.1.2)

Equipment Compartment Pressurization.

Pressurization of equipment compartments that are separate from the occupied compartments shall be regulated automatically and maintained at a pressure compatible with the most critical unit contained within the compartment. When the compartment pressurization is accomplished by controlling the outflow of air conditioning air or stored gases from the compartment, a second outflow valve or safety valve to prevent excessive positive and negative pressures shall be provided. The valve settings shall be determined by structural considerations. The compartment pressurization medium shall be supplied at pressure, temperature, moisture, and contamination levels compatible with the equipment specifications. The air used for equipment compartment cooling, when available at weight flows and pressure sufficient to provide pressurization, shall be used. If the cooling air is not suitable, the equipment compartment pressurization shall be provided from a high pressure stored gas system, use of temperature controlled engine bleed air, the pressure shall be maintained by controlling outflow of air from the compartment by means of a pressure regulator. A sagety valve shall provide positive pressure relief and negative pressure relief. The regulator shall be provided with means for holding the outflow portion in the closed position to accomplish equipment compartment ground pressure and leakage tests. Means to prevent leaving the valve in the closed position shall be provided. Moisture levels shall be compatible with the moisture levels specified in the equipment specification(s). Providing a means for indicating loss of equipment compartment pressurization to the crewmembers shall be given consideration. (3.1.1.1.3 and 3.2.2.1.3)

Note: Paragraph references are to Reference 5, MIL-E-38453A.

Table A4

Pressurization of Subsystem Reservoirs and Inflatable Seals,

Supply of Suits

Subsystem Reservoir Pressurization.

When the reservoirs of subsystems such as fuel, oil, hudraulic fluid, coolant fluid, and water are pressurized with air, the pressurization airflows shall be provided at pressure, temperature, moisture, and contamination levels compatible with the applicable subsystem specification requirements. Fail-safe provisions to prevent the entrance of hazardous fumes and fluids into environmental control, the environmental protection, and the engine bleed air systems shall be provided. The supply air flow rate and temperature shall be controlled to prevent autoignition. Fuel or fule vapors shall be prevented from backing up into the enbleed air system as a result of fuel expansion, even with the failure of a single component. The entrance of fule fumes into the engine bleed air system shall be prevented by fail-safe provisions consisting of two check valves or two similar redundancy means. Means for enabling ground test of fail-safe provisions for proper operation shall be incorporated. Where single failure can create the possibility of excessive fuel tank air temperatures, means for indicating excessive temperature to the crewmembers shall be provided. (3.1.1.1.5 and 3.2.2.1.5)

Inflatable Seal Pressurization.

Inflatable seals shall be sufficiently pressurized to provide effective sealing of closures when the compartment pressure is at a maximum, the aircraft is at maximum operational ceiling, and the pressurizing source is at a minimum pressure. The pressurization medium shall be supplied at pressure, temperature, moisture, and contamination levles compatible with each inflatable seal requirement. The inflatable seal system shall include pressure regulator, check valve, filter, and ground pressurizing and checkout connections in accordance with MS33565 and shall be located to be easily accessible during ground maintnenance. The inflatable seal system shall include provisions for deflation when on the ground. The seals shall remain inflated in the event of aircraft electrical system failure. (3.1.1.1.4 and 3.2.2.1.4)

Anti-g Suit Air Supply.

Pressurization air at pressure, moisture, and contamination levels compatible with the anti-g suit equipment shall be provided to each anti-g suit on aircraft in which the anti-g suits will be used. The temperature of the anti-g suit air supply shall be controlled between 50°F and 130°F. The compressed air source, when required, shall be in accordance with MIL-D-7890. (3.1.2.7)

Note: Paragraph references are to Reference 5, MIL-E-38453A.

Table A4

Pressurization of Subsystem Reservoirs and Inflatable Seals,

Supply of Suits - Continued

Pressure Suit Air Supply.

A supply of air at pressure, moisture, and contamination levels compatible with the pressure suit equipment shall be provided for each pressure suit on aircraft in which pressure suits will be used. The temperature of the pressure suit air supply shall be controlled between 55°F and 90°F. Pressure suit provisions shall be incorporated in accordance with Section 5B, Chapter 5 of the AFSC Design Handbook DH 2-3. (3.1.2.8)

Note: Paragraph references are to Reference 5, MIL-E-38453A.

Table A5A

Air Conditioning of Occupied Compartments

Performance and Functional Requirements

Cooling in Flight. Throughout the temperature and humidity range specified in MIL-STD-210 the cooling equipment shall have sufficient capacity to maintain the average compartment temperature at 70°F for all flight conditions, throughout the range from minimum to maximum engine power setting, except for transients of 30 minutes or less such as climb, idle descent, and high speed burst. For transient flight conditions of 30 minutes duration or less the average compartment shall not exceed 80°F. (5/3.1.1.2.1.1)

Cooling on Ground. During ground operation in all temperature and humidity conditions of Figure A1, when using either the aircraft propulsion engines operating at idle or an on-board auxiliary power unit, the cooling equipment shall be capable of preventing the average compartment temperature from exceeding 80°F. Transient cool down times of compartments following high temperature soaks shall be as specified in the weapon system specifications or held to a minimum if not specified. (5/3.1.1.2.1.1)

Surface Temperatures. The temperature of all surfaces except small surfaces which radiate heat to occupants shall not exceed levels which adversely affect human comfort. These temperatures shall not exceed 105°F, except during transient periods of 30 minutes or less at which time they shall not exceed 160°F. All surfaces in occupied compartments, which can be touched by personnel, shall be maintained at levels that will not cause discomfort if touched with the unprotected parts of the human body. (5/3.1.1.2.1.1.)

Warm-up Time. Air cycle air conditioning shall be capable of operating at full capacity within 60 seconds of initial operation after soaking in any ambient temperature from -65° to +160°F. (7/3.6.1.2)

Heating. The aircraft heating equipment shall be capable of maintaining an average compartment air temperature of at least 80°F for all ground and flight conditions when operating in cold day ambient conditions specified in MIL-STD-210. Floor areas which the crew members and passengers will be in contact with for extended time periods shall be maintained at or above 60°F during all flight conditions. Floor areas which crew members and passengers will not be in contact with for extended time periods shall be maintained during all flight conditions with an average floor temperature of at least 60°F with no areas colder than 40°F. The maximum floor temperature shall not exceed a level that is hazardous or uncomfortable. Minimum temperatures of radiant surfaces, except small local areas, to which occupants may be exposed in flight for periods longer than 30 minutes shall be 50°F. (5/3.1.1.2.1.2)

Note: Paragraph references are to Reference 5 (MIL-E-38453A) and to Reference 7 (MIL-A-83116A).

Table A5A

Air Conditioning of Occupied Compartments

Performance and Functional Requirements - continued

Temperature Control. Automatic temperature controls shall meet the following requirements:

(a) Steady state: hold average compartment air temperature within $\pm 3^{\circ}F$ of setting selected by crew.

(b) Transient: the time required to stabilize within $\pm 3^{\circ}F$ of the setting selected after extreme transients caused by engine power changes, aircraft maneuvers or change of selected temperature shall not exceed that specified by the airframe contractors detailed specification and shall be held to a minimum.

(c) Manual: an electrical or mechanical means of over riding the controller shall be provided. (5/3.1.1.2.1.3)

Distribution. Temperature variation between any two points in the envelope occupied by seated personnel shall not deviate more than $5^{\circ}F$ from the average compartment temperature. Temperature differences outside the envelope of seated personnel shall not vary more than $10^{\circ}F$ from the average compartment temperature. The velocity of the air moving past crew members or passengers shall not exceed 300 feet per minute. (5/3.1.1.2.1.4)

Ventilation. A fresh air ventilation rate of at least 20 cubic feet per minute per person shall be provided for the full complement of crew members and passengers during all flight and ground conditions, except that the minimum ventilation rate for passengers on high density personnel transports may be 13 cubic feet per minute per person. The minimum airflow rate into the compartments of pressurized aircraft for all flight conditions shall be at least 1.8 times the maximum allowable production leakage rate. (5/3.1.1.2.1.5)

Ram Air Ventilation. An emergency ram air ventilation system that will provide uncontaminated air as above during failure of the normal aircraft cooling provisions shall be incorporated in all aircraft that do not use ram air as the normal means of ventilation. (5/3.1.1.2.1.6)

Contamination. Air supplied to occupied compartments, regardless of origin, shall not cause compartment contamination levels in excess of the maximum allowed by MIL-STD-800 and Bulletin 526. (5/3.1.1.2.1.7)

Note: Paragraph references are to Reference 5, MIL-E-38453A.

Table A5B

Air Conditioning of Occupied Compartments

Design Requirements

Cooling. Cooling may be by air cycle refrigeration, vapor cycle refrigeration, ram air, compartment air, expandable coolants, heat storage materials, thermoelectric refrigeration or similar techniques. (5/3.2.2.2.1)

Vapor Cycle Refrigeration. See section 3.2.2.2.1.2 of MIL-E-38453A.

Air Cycle Refrigeration. See MIL-A-83116A. Some highlights are summarized below:

(a) it shall be an integral part of the ECS (7/3.5)

(b) non-operating components shall have a life equal to that of the weapon system (7/3.5.3.1)

(c) operating components which can be overhauled for not more than 65% of the initial cost shall have minimum endurance lives as follows (7/3.5.3.1 and 3.5.3.2)

Cargo and bomber aircraft	3000 hours
Fighter and trainer aircraft	2000 hours
Missiles	500 hours
All others	1000 hours

(d) the subsystem shall be designed for maintenance, other than overhaul of the air cycle machine, at organization and field maintenance levels (7/3.5.4.1)

(e) filters and water separator coalescers shall not, under normal conditions, require removal from the air vehicle for cleaning in less than 500 hours of operation (7/3.5.4.1)

(f) turbine inlet nozzles shall be replaceable as a single unit (7/3.7.1.13)

(g) the air cycle machine shall be so designed as to avoid adverse effect of entrained moisture or ice (7/3.7.1.11)

Elapsed Time Indicators. Refrigeration units shall have elapsed time meters reading up to 9999 hours which can be read easily without mirrors and not be easily damaged. (7/3.7.1.3)

Note: Paragraph references are to Reference 5 (MIL-E-38453A) and to Reference 7 (MIL-A-83116A).

Table A3B

Air Conditioning of Occupied Compartments

Design Requirements - continued

Water Separation. Water separators shall be installed as far as possible downstream from the turbine unless separation is by a regenerative heat exchange process. An integral bypass valve which will allow airflow around the separator if the normal passage is blocked by dirt or ice, so located that its operation will not be prevented by ice build up. Separators exposed to the possibility of freezing condition shall be protected by an anti freeze control. The valve controlling the warm air flow to prevent freezing shall fail closed. (3.7.4.1)

Lubrication. Air cycle machines and high speed fans which use wet sump lubrication shall not require changing or addition of oil at intervals of less than 500 hours of operation. Those using other types of lubrication shall not require changing or addition of oil at intervals of less than 1000 hours. (3.5.4.1)

Note: Paragraph references are to Reference 7, MIL-A-83116A.

Table A6A

Equipment Conditioning

Performance and Functional Requirements

Equipment and Equipment Compartments.

Conditioning as required by the equipment specifications and the results of analyses and evaluations accomplished in accordance with MIL-STD-890 and MIL-E-83210 shall be provided for equipment and equipment compartments. (3.1.1.2.2)

Electronic Equipment Cooling.

The cooling provisions for electronic equipment, excluding the means for distribution of the coolant media, shall provide cooling for an electronic heat dissipation load 25 percent greater than the on-board electronic equipment heat load of the first production aircraft. This excess capacity is intended for future equipment that may be added to the aircraft during service usage; therefore, an additional allowance in excess capacity for equipment that might be added during the development phase prior to production and for possible increases in heat dissipation of equipment over that assumed for the equipment at the start of the program shall be made in establishing the total system cooling capacity at the start of an aircraft development program. The appropriate environment for both operating and nonoperating equipment shall be maintained during all flight conditions and all aircraft ground operational conditions with ground ambient temperatures up to 125°F and ground humidity levels within the range defined by figure 1, including engines at idle speed. The ram air cooling systems for electronic equipment shall have provisions to assure that the equipment will not be adversely affected during the flight in rain with rain fall rates up to 6 inches per hour. (3.1.1.2.2.1)

Free Convection Air Cooling.

Compartments containing electronic equipment in accordance with MIL-E-5400, which are cooled by ambient free convection, shall be supplied with sufficient conditioned air to maintain the ambient temperatures, throughout the conditons of 3.1.1.2.2.1, within the specified maximum and minimum temperature and altitude limits for the particular class of equipment as defined in MIL-E-5400. Free convection cooled equipment shall be limited to the operating environment for which the equipment was designed and tested. (3.1.1.2.2.1.1)

Internally Forced Air Cooling.

Force air cooled equipment shall be provided with the cooling air temperature and weight flow specified in the equipment specification.

Note: Paragraph references are to Reference 5, MIL-E-38453A.

Table A6A

Equipment Conditioning

Performance and Functional Requirements - Continued

Temperature and pressure ambients compatible with the environment to which the equipment was designed and tested shall be provided. In instances where it is proposed to install equipment in compartments with ambient temperature that is more severe than the temperature to which the equipment has been tested, a thermal analysis that will show satisfactory functional and reliability performance may be acceptable in lieu of a retest. Cooling air forced directly over the surface of miniaturized or basic electronic components shall be totally void of entrained moisture. (3.1.1.2.2.1.2)

Cold Plate Forced Convection Air Cooled.

Air supplied to cold plate forced convection cooled units shall meet the temperature and weight flow or heat rejection requirements of each equipment specification. (3.1.1.2.2.1.3)

Forced Convection Liquid Cooled.

Liquid coolant supplied to forced convection liquid cooled equipment shall be at flows, temperatures, and pressures specified by the equipment detail specifications. All line replaceable units of the liquid cooling loops shall have self-sealing disconnects. Liquid coolant connections to the equipment being cooled shall be a self-sealing and a quick-disconnect type. (3.1.1.2.2.1.4)

Temperature Control.

The range and rate of fluctuation between minimum and maximum electronic equipment operating temperatures shall be mimimized and should not exceed that necessary to provide the specified equipment reliability except during emergency ram air operations. The inlet cooling air temperature and flow rate to forced and ambient cooled electronic equipment should be controlled to prevent overcooling and assure no problems due to moisture. (3.1.1.2.2.2)

Distribution.

The cooling air shall be distributed to each unit of equipment in accordance with the cooling requirements determined as specified in 3.1.1.2.2 and 3.1.1.2.2.1. When plenum chambers (integrated equipment racks and distribution system) are used to supply cooling air to several units, the effects of temperature rise and pressure loss shall

Note: Paragraph references are to Reference 5, MIL-E-38453A.

Table A6A

Equipment Conditioning

Performance and Functional Requirements - Continued

be taken into account in determining cooling requirements. Allowances for improper flow balancing and system leakage shall be included in the cooling requirements. Cooling air ducts routed through compartments in which high ambient temperatures or humidity can exist shall be insulated to prevent excessive heat gain or condensation. When equipment is cooled by exhaust air from occupied compartments, sufficient redundancy shall be incorporated to insure that no single failure in the occupied compartment cooling circuit will result in equipment overheat. Flexible ducts shall be in accordance with MIL-H-8796. All other ducting shall meet the flame resistance requirements of MIL-H-8796. (3.1.1.2.2.3)

Contamination.

Air delivered to the interior portions of internally forced convection air cooled electronic equipment shall not contain more than 0.1 gram of solid contaminants per pound of air, and 95 percent of the particles shall be less than 20 micron in size, and no particle shall be greater than 50 micron. (3.1.1.2.2.4)

Emergency Cooling.

In the event of failure of the normal mode of cooling, an alternate cooling mode through the use of ram air or another cooling unit if available shall be provided for all mission essential electrical and electronic equipment, weapons, and any other applicable compartments, which are not normally cooled by ram air, to enable sufficient cooling of the equipment for mission completion as long as ram air temperatures are below 120°F. The emergency ram air controls shall be designed so that the normal supply of cooling air to the equipment and equipment compartment is shut off and compartment pressure is released when emergency ram air is selected. Reverse flow through the emergency ram air circuit shall be prevented unless it is configured to act as a dump function. (3.1.1.2.2.5)

Note: Paragraph references are to Reference 5, MIL-E-38453A.

Table A6B

Equipment Conditioning

Design Requirements

Equipment and Equipment Compartment.

Temperature control for equipment and equipment compartments shall be automatic. An indication of overtemperature conditions shall be provided to the crewmembers. (3.2.2.2.5.2)

The cooling air shall be proportioned to the equipment in accordance with the cooling requirements of the applicable specification. Insulation to prevent excessive heat gains shall be installed around the equipment and equipment compartment distribution ducts when ducting is routed through compartments capable of high ambients. When cooling of equipment is accomplished with the air exhausted from occupied compartments, sufficient redundancy shall be incorporated in the provisions that induce flow to the equipment to insure that no single failure will results in equipment overheat. Flexible ducts shall be in accordance with MIL-H-8796. (3.2.2.2.6.2)

Contamination Control.

When filters are used for contamination control, the quantity and type of filters shall be minimized. The filters shall be located for easy accessibility for inspection, cleaning, and replacement. The filters on aircraft that may be exposed nuclear particulate matter and chemical and biological warefare agents shall be designed with a remote handling capability. (3.2.2.2.8)

Note: Paragraph references are to Reference 5, MIL-E-38453A.

Table A6C

Environmental Conditions For Convection Cooled Electronic Equipment

Equipment Operating Temperature Extremes (Degrees C)			Combined Temperature -Altitude			Temperature Shock Degrees C	Equipment Op or Non-Op	Equipment	Nonoperating
Continuous (Degrees C)	Intermittent	Short-Time	Continous	Intermittent	Short-Time		Altitude	Temperature Extremes	Temperature Shock
-54 to +55	30 min at +71	- -	Curve A Figure A4(a)	Curve B Figure A4(a)	- -	-54 to +71	Sea level to 50,000 ft	-57 to +85	-57 to +85
-54 to +55	30 min at +71	- -	Curve A Figure A4(a)	Curve B Figure A4(a)	- -	-54 to +71	Sea level (1) to 30,000 ft	-57 to +85	-57 to +85
-40 to +55	30 min at +71	- -	Curve A Figure A4(a)	Curve B Figure A4(a)	- -	-40 to +71	Sea level (1) to 15,000 ft (16.89 in Hg)	-57 to +85	-57 to +85
-54 to +71	30 min at +95	- -	Curve A Figure A4(b)	Curve B Figure A4(b)	- -	-54 to +95	Sea level to 70,000 ft	-57 to +95	-57 to +95
-54 to +95	30 min at +125	10 min at +150	Curve A Figure A4(c)	Curve B Figure A4(c)	Curve C Figure A4(c)	-54 to +125	Sea level to 100,000 ft	-57 to +125	-57 to +125
-54 to +125	30 min at +150	10 min at +260	Curve A Figure A4(c)	Curve B Figure A4(c)	Curve C Figure A4(c)	-54 to +150	Sea level to 100,000 ft	-57 to +150	-57 to +150
-54 to +95	30 min at +125	- -	Same as Class 3 (2)	- -	- -	-54 to +125	Sea level to 2,000,000 ft	-57 to +125	-57 to +125

(1) Altitude range is for operation only, Classes 1A and 1B equipment shall withstand a non-operating altitude of 40,000 ft.

(2) For altitude above 100,000ft the equipments surrounding environment shall not exceed 71 degrees C and means shall be available for rejection of heat into the surroundings by convection, radiation or other means.

Table A7A

Anti-Icing of Non-Transparent Areas

Performance and Functional Requirements

Areas to be Protected. Protection is to be provided as follows (5/3.1.2.6)

Radomes and antennas if required to maintain radar or communications efficiency.

Flight surfaces, pylons and external stores all on which ice build up or shedding would cause flight hazard, engine damage or significant deterioration of performance.

Ram air inlets Ram air inlets and emergency ram air inlets supplying cooling to air conditioning packs, electronic equipment, and compartments unless operation under icing conditions is possible without detrimental ice build up that could seriously impair air conditioning performance or equipment cooling or damage system components. Protection is to be provided for guide vanes or at abrupt changes in direction.

Meteorological Conditions. As shown in Figures A2 and A3. (5/3.1.2.6)

Flight Conditions. The following are the design flight conditions:

(1) Climb at speed for maximum rate of climb.

(2) Cruise at speed for maximum range at normal operating altitude, if this is less than 20,000 feet.

(3) Descent at speeds, rate of descent, and engine power as recommended by the manufacturer and approved by the procurring activity. (9/3.3.2)

If the design mission of the aircraft requires intermittent operation below 20,000 feet typical conditions including high and low speed shall be included as design points. (9/3.3.2.1)

Ground Operation. The system shall be capable of operation on the ground. (9/3.6.5)

Anti-Icing Standards for Speeds less than Curve A of figure A4, complete evaporation of all impinging water droplets at 15°F unless the entire surface is heated, in which a running-wet surface is allowable with a minimum surface temperature of 35°F at 0°F ambient temperature. (9/3.3.2)

For Speeds greater than Curve A but less than Curve B the system need only provide a running-wet surface at 0°F ambient since the runback will not freeze. (9/3.3.4)

Note: Paragraphs are to Reference 5 (MIL-E-38453A) and to Reference 9 (MIL-A-9482).

Table A7A

Anti-Icing of Non-Transparent Areas

Performance and Functional Requirements - continued

For speeds greater than Curve B no anti-icing system is required except for landing and take off. For this case the contractor shall recommend and the procurring activity decide whether an anti-icing system is needed. (9/3.3.5)

Note: Paragraph reference is to Reference 9, MIL-A-9482.

Table A7B

Anti-Icing of Non-Transparent Areas

Design Requirements

Heat Source. Thermal anti-icing systems must conform to MIL-A-9482. The primary heat source shall be hot air obtained from compressor bleed, exhaust gas heat exchangers, mixtures of compressor bleed air and exhaust gases or combustion heaters. Electrical heating may be used for small areas where it is more convenient or where it induces less penalty to aircraft performance. (9/3.5/1)

Scoops and ducts leading to exhaust gas heat exchangers or combustion heaters which provide heat for anti-icing shall be electrically heated. (9/3.5.2)

When more than a single source of heated air is used to furnish heat for the anti-icing system, the several sources shall be manifolded together so that in the event of the failure of one heat source the remaining heat supply can be distributed to all the surfaces to be anti-iced. (9/3.5.3)

Hot air cycle or electrical cycle de-icing and anti-icing may be used when designed and installed in accordance with an approved contractor specification. (5/3.2.3.5.3)

Note: Paragraph references are to Reference 5 (MII-E-38453A) and to Reference 9 (MIL-A-9482).

Table A7C

Anti-Icing of Non-Transparent Areas

Contractor Flight Test Requirements

From MIL-E-38453A, 2 December 1971

Flight Surface, Inlet, and Radome Anti-Icing.

Flight testing of flight surface and inlet anti-icing provisions shall be accomplished in accordance with MIL-A-9482 and demonstrated by flight in natural or simulated icing conditions. Flight testing of radome anti-icing provisions shall be accomplished, with procedures given in MIL-A-9482 for flight surfaces, and demonstrated by flight in natural or simulated icing conditions. When flight surface or inlet anti-icing provisions are not provided, flights shall be made with simulated ice build-up shapes installed to demonstrate that performance is not degraded below a minimum acceptable level. (4.10.7.7)

From MIL-A-9482, 2 September 1954

Flight Tests.

Flight tests shall be conducted to demonstrate control system operation, temperature indication operation, operation of overheat warning or control, freedom from overheating and detrimental effects of differential expansion. In addition, a complete thermal survey shall be conducted to determine the heat available. These tests shall be conducted in dry air unless otherwise specified by the procuring activity, but should be conducted with sufficient detail and accuracy to permit extrapolation of the results to actual icing conditions. Flight conditions shall include at least the following:

(1) Normal takeoff and climb to operating altitude
(2) Normal descent and landing
(3) Level flight at speed for maximum endurance, maximum speed, and an intermediate speed approximately halfway between these speeds at 5,000, 12,000, and 20,000 feet altitudes (4.2.3)

Instrumentation shall be installed to determine the qunatity and temperature of air from each heat source and the temperature and quantity of airflow in all main distribution ducts. At least 3 wing stations on one side of the airplane and 2 stations on one horizontal and vertical tail surface shall be instrumented to proves a chordwise profile of exterior and inner skin temperatures as well as temperature drop and airflow through the double skin passages. The remaining wing and tail surfaces shall have sufficient instrumentation to insure that they are receiving the same heat supply as the completely instrumented

Table A7C

Anti-Icing of Non-Transparent Areas

Contractor Flight Test Requirements - Continued

section. Sufficient structural temperatures shall be measured to ensure that structuraloverheating does not occur. Shielded thermocouples shall be used for measuring air temperatures in locations where ther is a substantial difference between air temperature and the surrounding metal. If there are discontinuities in the heated areas, sufficient temperature measurements shall be made to determine the effect of the heat flow from the heated to the unheated area. Thermocouples used on aircraft to be tested by WADC shall be copper constantan to reduce the effects of corrosion on instrumentation reliability. Surface temperatures and heat supply shall be measured on scoops or other miscellaneous items provided with anti-icing protection. (4.2.3.1)

Table [illegible]8A

Anti-Icing of Transparent Areas

Performance Requirements

Areas to be Protected. Windshield and bombardiers panel and all areas essential to the mission of the aircraft such as scanning and sighting stations, astrodomes, camera windows, areas required by the pilot or co-pilot to accomplish evasive action, areas required by the flight engineer to check operation of engines or control surfaces shall be protected. (6/3.7 and 3.8.1)

Flight Conditions. All conditions of flight.

Performance. Windshield and bombardiers panel: heat to be supplied to exterior as required in MIL-T-5842A paragraph 3.7.1. Other mission essential areas: sufficient to maintain primary function. (6/3.8.1)

Note: Paragraph references are to Reference 6, MIL-T-5842A.

Table A8B

Anti-Icing of Transparent Areas

Design Requirements

Methods. May be hot air jet blast, electrical conductive coatings or infrared radiation. For areas other than windshields and the bombardiers panel liquid spray or extendable shields or deflectors may also be used. (6/3.7.1.1 and 3.8.3)

Overheat Protection. If the design is such that overheating is possible under some ground or flight conditions temperature limiting devices shall be installed. If electrically conductive coatings are used a separate control sensor, overheat sensor, temperature controller and power source shall be provided for each panel. Positive power-off action shall result in the case of a control circuit malfunction or failure that could result in overheat. (6/3.4.1.2, 3.11.3 and 5/3.2.5.1)

Control. When electrically conductive coatings or infrared sources are used they shall incorporate an automatic temperature control operated by a temperature sensing element in the transparent area. A multi position switch having not less than an off, low (approximately 1/2 total power) and high position shall be used to operate the system. (6/2.11.1.3)

Note: Paragraph references are to Reference 5 (MIL-E-38453A) and to Reference 6 (MIL-T-5842A).

Table 19A

Defrosting and Defogging of Transparent Areas

Performance Requirements

<u>Areas to be Protected.</u> Windshields and bombardiers panel. All transparent areas essential to the mission of the aircraft such as scanning or sighting stations, astrodomes, camera windows, areas required by the pilot or co-pilot for evasive action, areas required by the flight engineer to check operation of engines or control surfaces, areas required for taxiing shall be protected. (3.9.1)

<u>Flight Conditions.</u> All conditions of flight, including flight at constant altitude. Additionally for combat aircraft, during a rapid descent from altitude (maximum rate of descent at limit dive speed from service ceiling to sea level and rate of descent at recommended descent speed). (3.9.4 and 3.9.5)

<u>Atmospheric Conditions.</u> With saturated air within the compartment at all temperatures and altitudes, including moisture output of 0.5 pounds per hour per occupant. External ambient air temperature -65°F from sea level to 25,000 feet, then decreasing linearly with increase in altitudes to -90°F at 50,000 feet. Constant at -90°F above 50,000 feet. (3.9.2.1 and 3.9.3)

<u>Ground Operation.</u> Systems shall be capable of clearing the windshield and those areas required for ground handling and operation during engine warm-up, taxiing, take-off and touchdown. (3.9.7)

<u>Note:</u> Paragraph references are to Reference 6, MIL-T-5842A.

Table A9B

Defrosting and Defogging of Transparent Areas

Design Requirements

Methods. May consist of hot air jets, double panes with hot air between panes, double panes with dry air insulating gap, electrically conductive coatings, infrared radiation, humidity control of cabin air or any combination of these methods. (6/3.9.6.1)

Overheat Protection. If overheating of the transparent area or any part of the system is possible under some ground or flight conditions, the temperature limiting devices shall be provided to prevent this overheating. (6/3.11.3)

Control. If hot air is used, the overheating effects in occupied compartments is to be minimised. If a power operated shut off valve is used a manual backup shall be provided. When electrically conductive coatings or infrared sources are used solely for defrosting and defogging (i.e., not for anti-icing) they shall incorporate an automatic temperature control regulated by means of a temperature sensing element in the transparent area and operated by an "ON-OFF" switch. (5/3.2.3.1 and 6/3.11.1.4)

Chemical Humidity Control. If chemicals are used to control humidity of the cabin or transparent area defogging and defrosting, consideration shall be given to a continuous system in which the reactivation process is contained within the system. If a self reactivating system is not used the chemicals shall be in a container which may be readily replaced or removed for reactivation. The minimum allowable period between replacements or reactivations shall be 10 flights under the maximum condition of moisture removal. (6/3.9.6)

Note: Paragraph references are to Reference 5 (MIL-E-38453A) and to Reference 6 (MIL-T-5842A).

Table A10

Removal of Rain and Snow from Transparent Areas

Areas to be Protected. Pilot and co-pilot windshields. Sensor windows for all in-flight conditions for which sensor operation is required. (5/3.1.2.2 and 3.1.2.3)

Weather Conditions. Heavy rain (0.59 inches per hour, 1500 micrometer median droplet diameter), snow, and excessive rain (.16 inches per hour, 2300 micrometer median droplet diameter). (5/3.1.2.2)

Flight Conditions. A sufficient area shall be cleared in heavy rain and in snow under the following conditions:

(1) ground taxi, take off, landing approach and landing

(2) in-flight refuelling, if required below 20,000 feet

(3) level flight at 1.6 times the stall speed at maximum weight with flaps and gear retracted for fixed wing aircraft

(4) maximum cruise speed for rotary wing aircraft

In excessive rain sufficient clearance shall be provided to enable a safe landing. (5/3.1.2.2 and 3.1.2.3)

Area to be Cleared. This is established by rain tunnel tests on a mockup. (5/3.1.2.2)

Methods. Jet blast, rain repellant or wipers. If jet blast is used it must provide sufficient flow for all ground and flight conditions including the minimum power settings normally associated with descent, flare, throttledown and taxi. Excessive window temperatures shall be sensed and a caution light provided. (5/3.2.3.2)

Note: Paragraph references are to Reference 5, MIL-E-38453A.

Table A11

Removal of Insects, Salt and Dust from Transparent Areas

When Required. When missions of the aircraft require low level flight over the oceans or along the coast (salt) or over land (insects and dust). Vertical take off and landing aircraft shall have a washing system for maintaining the pilot and co-pilots windshield free of dust. (5/3.1.2.4 and 3.1.2.5)

Areas to be Protected. Pilot and co-pilots windshield and sensor windows. (5/3.1.2.4 and 3.1.2.5)

Duration. Maximum duration of low level flight during one mission. (5/3.1.2.4 and 3.1.2.5)

Insect Concentration. One 120 milligram insect for 20,000 cubic feet of air. (5/3.1.2.5)

Washing System. This shall include a refillable reservoir with drainage provisions, a means for determining fluid level, and a bleed purging line or a nozzle drain. The washing fluid shall be non-toxic, nonflammable, non-corrosive and shall not have any adverse effects on the windshield or any other aircraft materials. If freezing of the washing fluid can occur then

(a) the fluid storage and supply equipment shall not fail as a result of repeated freeze and thaw cycles

(b) the fluid shall be provided to the transparency in sufficient quantity when required. (5/3.2.3.4)

Note: Paragraph references are to Reference 5, MIL-E-38453A.

Table A12

Comparison of Environmental Protection Requirements for Transparent Areas

ENVIRONMENTAL PROTECTION	AREAS TO BE PROTECTED	FLIGHT CONDITION	METHODS
Anti icing	Windshield, bombardiers panel, sensor windows, evasive action, flight engineers windows.	All conditions of flight	Hot air jet, electrical, infrared. Sensor windows may use spray, shields/deflectors
Defrost/Defog	As above plus areas required for taxiing.	All conditions of flight For combat aircraft, rapid descent. Ground operation (warm up, taxiing, take off, touch down)	Hot air jet, electrical, infrared, double panes, humidity control.
Rain/Snow	Heavy Rain Windshields, sensor Excessive Rain Enough for a safe landing	Taxi, take off, approach, landing. Inflight refuelling if below 20,000 feet. Level flight -1.6 x stall (fixed wing) - max cruise (rotary wing)	Jet blast/rain repellant/wipers
Dust, Salt, Bugs	Windshields + sensor windows	Low level flight	Washing fluid

Table A 13

Oxygen System Requirements

Regulators.

Panel mounted: An automatic diluter demand-pressure breathing regulator, in accordance with MIL-R-25410 or MIL-R-83178 (MS27599) as applicable, shall be installed at each permanent and temporary crew station in the aircraft. The pilot's panel mounted regulator shall be located in accordance with MIL-STD-203. The crew member's regulator shall be in the crew member's field of vision so that he can readily read the regulator without more than turing his head and with minimum interference with his flight duties. The regulators shall be located as close to the stations as is required to reach the regulator by normal extension of the crew member's arm. The regulators shall be located so that they cannot be damaged by movement of personnel around them and may be mounted vertically or horizontally. The panel mounted breathing regulator shall be installed with flexible hose for both inlet and outlet ports, so that the regulator may be front serviced for both installation or removal. (10/3.6.3.1 and 11/3.6.2.1)

Non-panel mounted: A manual shut-off valve shall be provided at each crewmember station where a seat, chest, or head mounted regulator is to be used. This valve shall control the oxygen flow to the regulator and provide means for stopping the flow from a defective quick disconnect or a damaged supply hose. Storage provisions shall be made for chest mounting regulators to prevent damage or contamination during servicing and ingress-egress actions. Non-panel mounted regulators shall be installed as specified by the procuring activity. (10/3.6.3.2 and 11/3.6.2.2)

Gauges and Indicators. Liquid oxygen totalizing quantity indicators shall be provided at the pilots or co-pilots station of aircraft in which more than one converter is installed, with a repeater indicator in each isolated flight compartments. The indicator shall be within the normal field of vision of the pilot/co-pilot/crew member so that he may see the gage when in normal operating of flight position without turning his head and with minimum interference with his flight duties. (10/3.5.1 and 3.6.2)

With gaseous oxygen systems indicating instruments shall be provided at those crew stations not provided with panel mounted regulators. Both pilot and co-pilot shall have complete indicating instruments while the other crew members shall have only flow indicators, except when mask, helmet or chest mounted regulators provide obvious evidence and sensorial perception of oxygen flow. Each additional crew compartment shall have a pressure gage. A pressure gage shall be provided in the passenger compartment so as to be readily visible to a crew member. (11/3.5.4). Note: Paragraph references are to Reference 10 (MIL-D-19326F) or 11 (MIL-D-RG83B).

Table A 13

Oxygen System Requirements (continued)

Location. The oxygen equipment, tubing, and fittings shall be located as remotely as practicable from fuel, oil, hydraulic, water injection, storage battery systems, exhaust stacks and manifolds, electrical and radio systems. Insofar as practicable, oxygen lines shall not be grouped with lines carrying flammable fluids away from oxygen lines, fittings, and equipment. Whenever possible, cylinders shall not be in line with the plane of rotation of a turbine or propeller. Components of the oxygen system shall not be installed where they will be subjected to temperatures in excess of that specified in the individual component specifications, and no part of the system shall be installed in an area which will be subjected to a temperature of 250°F (121°C) (gaseous oxygen) or 350°F (176°C) (liquid oxygen) or greater. Oxygen cylinders or converters shall not be located near equipment that dissipates a high quantity of heat. (10/3.5.6 and 11/3.5.5).

If two or more gaseous oxygen cylinders are installed they shall be separated as much as practicable to minimize combat vulnerability. (11.3.6.1).

Filling. The installation shall also provide for replenishing the oxygen sypply by connecting an external filling source directly to the filling valve. The filling point shall be located such that the time for gaining access for connecting the external filling source shall not exceed one man minute and shall not create a hazard for servicing personnel. 10/3.6.1 and 11/3.6.1).

Note: Paragraph references are to Reference 10 (MIL-D-19326F and to Reference 11 (MIL-D-8683B).

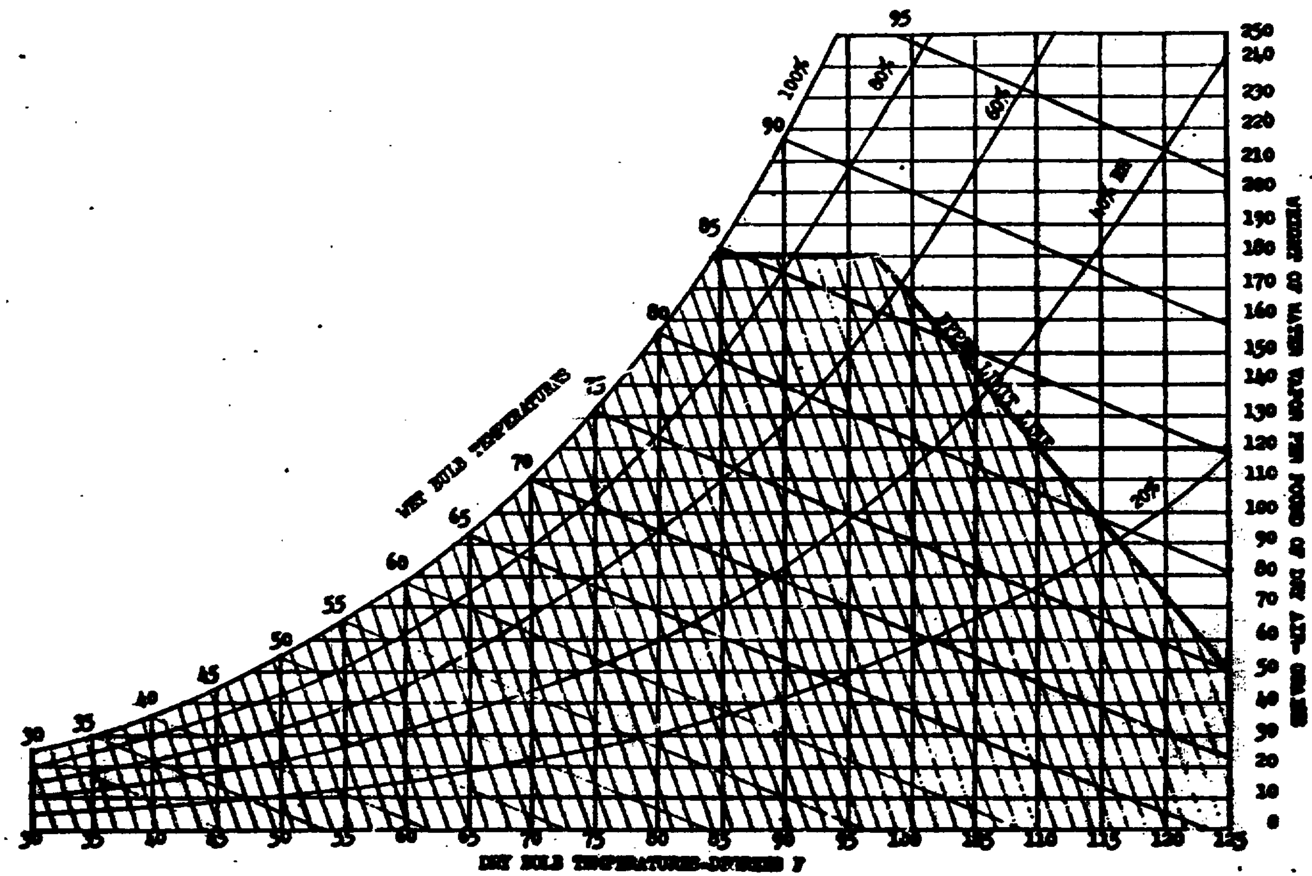


FIGURE D.1. Ground Level Design Humidity Range

(1. ALTITUDE; SEA LEVEL TO 22,000 FEET
(2) MAXIMUM VERTICAL EXTENT; 6,500 FEET
(3) HORIZONTAL EXTENT; 20 STATUTE MILES

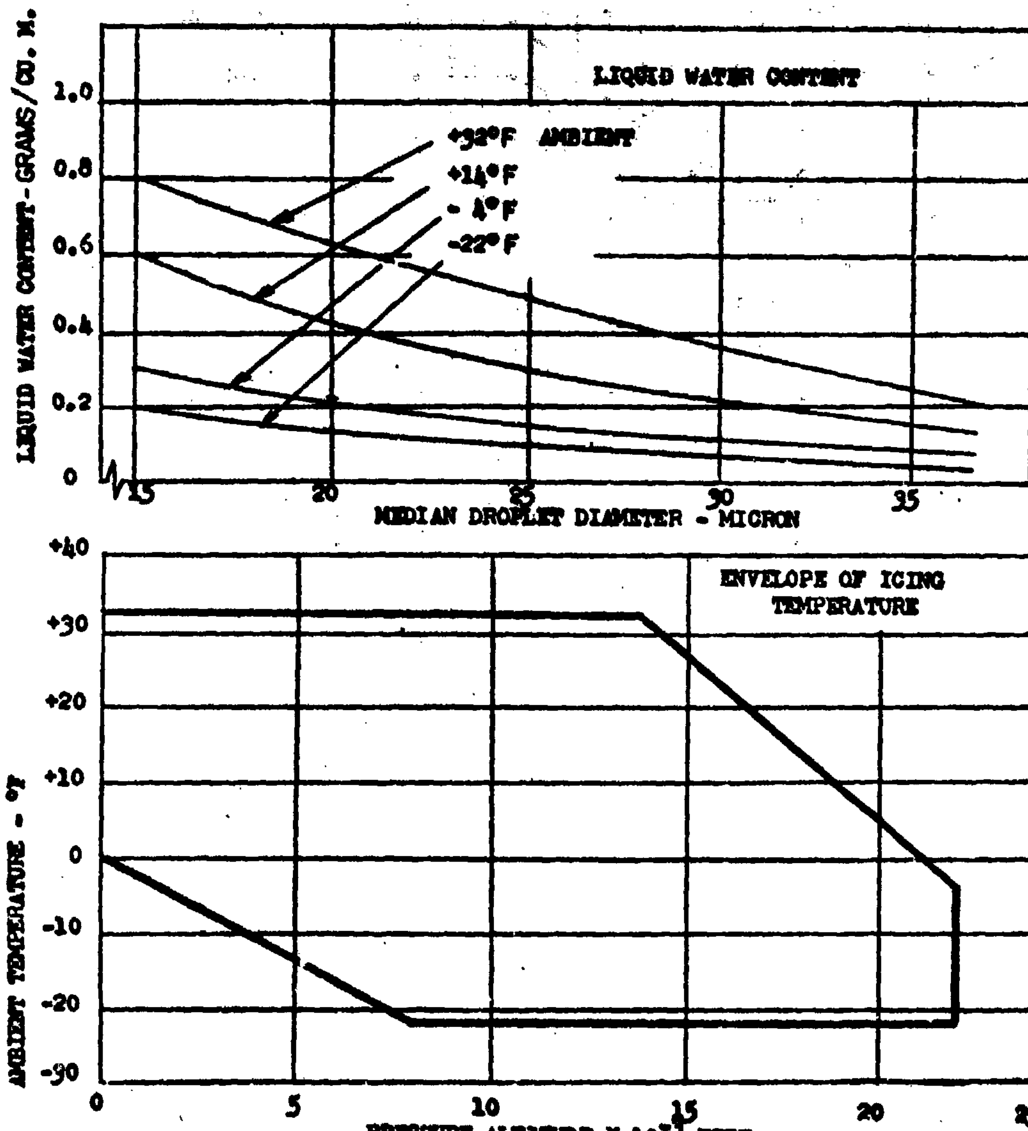


FIGURE A2. Continuous Maximum Icing Conditions

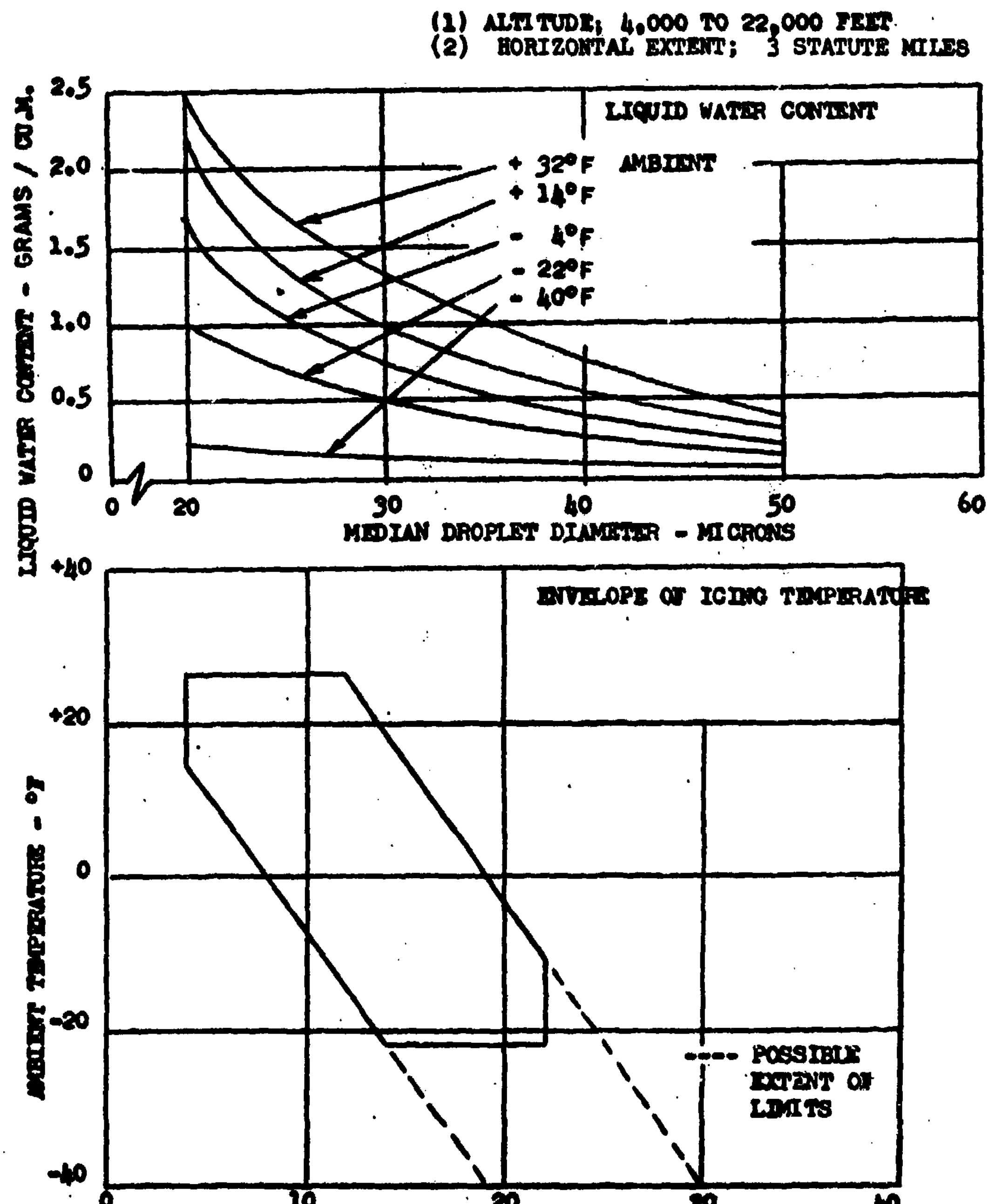
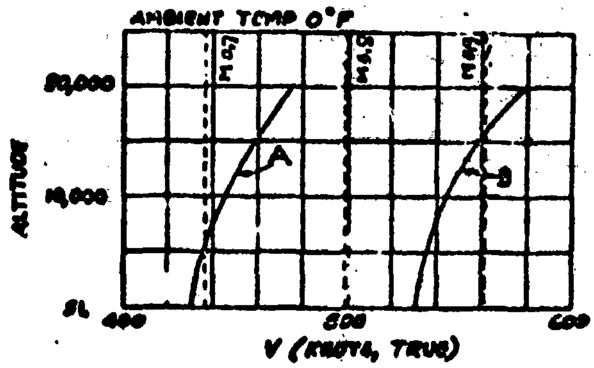


FIGURE A3 Intermittent Maximum Icing Conditions



CURVE A - SPEED ABOVE WHICH RUNBACK DOES NOT FREEZE

CURVE B - SPEED ABOVE WHICH ANTI-ICING SYSTEMS ARE NOT REQUIRED BY THIS SPECIFICATION

NOTE - CURVE "A" IS FOR AN ALUMINUM ALLOY SKIN AFT OF THE HEATED AREA. IF THE CONDUCTIVITY OF THE SKIN IS APPRECIABLY DIFFERENT FROM ALUMINUM ALLOY CURVE "A" CAN NOT BE USED AND THE SPEED AT WHICH RUNBACK DOES NOT FREEZE MUST BE CALCULATED FOR THE PARTICULAR CONSTRUCTION USED.

Figure A4 Effect of Speed on Icing Requirements

APPENDIX B

EXAMPLE OF TEST INFORMATION SHEET

AFFTC TEST INFORMATION SHEET (TIS) (F-15 TEST PROGRAM)	DATE 31 October 1973	PAGE 1 OF 11 PAGES
TITLE OF TEST: Environmental Control System Evaluation	VEHICLE TYPE: F-15	TIS NUMBER: 41
	EFFECTIVITY: F-3, 10, & 14	REVISION: A

TEST TIME	TEST PERIOD	TESTING ACTIVITY	HAZARDOUS/UNUSUAL TEST
[ ] PRIMARY	Dec 73 - Feb 74	AFFTC/DOVJ	None
	LOCATION OF TEST	TIS TYPE	SECURITY CLASSIFICATION
[X] CONCURRENT	Edwards AFB	[ ] PLAN [X] PROCEDURAL	UNCLASSIFIED

1.0 **REFERENCES**:

1.1 PID CP76301A328A086A, F-15 Air Vehicle Environmental Control Subsystems.

1.2 Contractor DT&E TIS for ECS, CP086FF002.01, 15 June 1973.

1.3 T.O. 1F-15A-1, Flight Manual F-15A.

1.4 AFFTC Test Information Sheet number (TIS) 1AFDT&E-3, 3 October 1973.

1.5 DR 14-13, "Smoke and fumes in cockpit," 16 October 1973, AFFTC.

1.6 DR 53-47, "Cockpit airflow surges and pressurization fluctuations were experienced inflight," 20 October 1972, AFFTC.

1.7 AFFTC TIS AFPE #5, 1 May 1973.

1.8 F-15 AFDT&E Plan, AFFTC, Edwards AFB, Ca., July 1972.

1.9 DR 117-107, "Insufficient cooling airflow at low power settings is causing the AV Hot light to illuminate," 6 March 1973.

1.10 Threshold Limit Values, American Conference of Governmental Industrial Hygienists (MIL-STD-1472, para 5.8.1.2).

1.11 MCAIR A048, "Reliability Program Plan."

1.12 DR 3-3, "ECS Ground cooling fan failures," 1 December 1972.

1.13 DR 47-41, "Excessive ECS component failures," 19 October 1972.

1.14 MIL-A-83116A, "General Specification for Aircraft Air Conditioning Subsystems," 31 March 1971.

CP76301A328A083A (S), F-15 Avionics Subsystem, September 1973.

ACTION	OFFICE OR POSITION/PHONE	SIGNATURE	DATE
PREPARE	Capt Willmann/73883	Robert L. Willmann	10 DEC 1973
REVIEW	AFFTC/DOVJE/DOEES	Joseph F. [illegible]	13 Dec 73
REVIEW	AFFTC/DOVJ/TACD-J	[illegible]	DEC 14 1973
REVIEW	AFFTC/DOV	[illegible]	21 DEC 1973
APPROVE	AFFTC/DO	[illegible]	21 DEC 73

AFFTC FORM JAN 73 0-128

[redacted]

TIS NO.	REVISION
41	A
PAGE 2 OF 11 PAGES	
DATE 31 October 1973	

2.0 ENVIRONMENTAL CONTROL SUBSYSTEM DESCRIPTION:

The ECS provides cooling and pressurization, as required, for the cockpit and avionics, windshield anti-fog and anti-ice, anti-G, canopy seal, and fuel pressurization. The ECS uses high temperature, high pressure thirteenth stage engine compressor bleed air from either or both engines. Engine bleed air passes through the primary heat exchangers and is cooled below the auto ignition temperature of fuel, oil, and hydraulic fluid prior to passing through the engine compartment firewall. The Air Cycle Air Conditioning Subsystem (ACACS) takes this preconditioned bleed air and further conditions it to meet cockpit and avionics environmental requirements. The system incorporates a liquid cooling system for the radar transmitter. The cockpit will start to pressurize at 8,000 feet PA and maintain a cabin pressure altitude of 8,000 feet until approximately 23,100 feet. Above 23,100 feet the cabin regulator maintains a 5 PSID below the actual aircraft altitude. Some modifications to the original ECS are: removal of the liquid rain repellant system, removal of the ground cooling fan and replacement with ejector nozzles on the secondary heat exchanger, and redesigned cabin and avionics control valves, controllers, sensors, and the autogenous temperature control system.

3.0 OVERALL OBJECTIVE:

To determine whether the Environmental Control System of the F-15 is operationally suitable. Tests will be conducted primarily at the AFFTC, with some of the test objectives being repeated under extreme environmental conditions in the climatic laboratory, Alaska, Panama, and El Centro, California. Specific objectives will be expanded at a later date to include extreme environmental conditions, where applicable.

4.0 SPECIFIC OBJECTIVES:

4.1 OBJECTIVE: Evaluate the normal operations of the ECS throughout the design flight and ground envelope of the F-15 aircraft.

4.1.1 Requirement References: Ref. 1.1, 1.2, 1.3, 1.4, 1.7, 1.8, 1.10 and 1.11

4.1.2 Test Conditions: All altitudes up to the operational ceiling of the aircraft and all airspeeds up to Vmax at various altitudes. Ground runs with two engines and single engine will be performed. A ground run following a heat soak will also be conducted. All points will be on a ride along basis. Specific conditions to be flown are:

Flight Cond.	Power Setting	Maneuver
Takeoff	Mil	Field elev. to 2500 AGL
Takeoff	A/B	Field elev. to 5000 AGL
Climb	Mil	5000 to 50,000 PA
Climb	A/B	5000 to 50,000 PA
Descent/climb	As Req'd	Weapons delivery mode (roll-in at 10,000 ft MSL and 1,000 ft AGL recovery)
Cruise	Mil	5,000 PA level
Vmax	A/B	5,000 AGL level
Cruise	Max Endurance	20,000 PA level

Flight Cond.	Power Setting	Maneuver
Cruise	Max Endurance	35,000 PA level
Cruise	Max Endurance	50,000 PA level
Vmax	A/B	50,000 PA level
Rapid Descent	As Req'd	50,000 PA to 1,000 AGL
Normal Descent	As Req'd	50,000 PA to 1,000 AGL

4.1.3 Test Procedure: During all flights the pilot will utilize the ECS and monitor the performance of the ECS for adequate cooling/heating, pressurization, airflow, anti-fogging, fuel tank pressurization (feeding), fumes, etc. The pilot will report any discrepancies, and, if appropriate, he will take an instrumentation record. Automatic and manual temperature control modes will also be investigated by selecting various settings and allowing temperatures and flow rates to stabilize.

4.1.4 Support Requirements: Telemetry, when available to support the primary objectives.

4.1.5 Data: Pilot comments, time history plots of selected parameters in Table 1.

4.2 OBJECTIVE: Evaluate cockpit environment for smoke and fumes throughout AFDT&E program.

4.2.1 Requirement Reference: Ref 1.1, 1.5, and 1.10.

4.2.2 Test Conditions: Same as 4.1.2.

4.2.3 Test Procedures: Same as 4.1.3.

4.2.4 Support Requirements: Same as 4.1.4.

4.2.5 Data: Same as 4.1.5.

4.3 OBJECTIVE: Evaluate ability of the ECS to prevent airflow or pressurization surges.

4.3.1 Requirement References: Ref 1.4 and 1.6.

4.3.2 Test Conditions:

Press Alt (feet)	Airspeed (IMN)	Throttle(s) (RPM)*	Air Source (Position)
Ground	0.0	68 - MIL - 68%	BOTH
10K MSL	0.4	72 - MIL - 75%	BOTH
25K	0.6	75 - MIL - 75%	BOTH
30K	0.9	80 - MIL - 80%	BOTH
45K	0.9	80 - MIL - 80%	BOTH

* RPM range will be maximum allowable by contractor.
: Requires engines sequence number 036 or subsequent.

4.3.3 Test Procedures: Stabilize at points in para 4.3.2 and make rapid throttle movements, first with one throttle at a time, then with both throttles simultaneously. If ECS surges are encountered, repeat maneuver with air source selector in LEFT, and in RIGHT to try to isolate which bleed air system is causing the problem.

4.3.4 Support Requirements: Engines with fast acceleration package (036 or subsequent are required.

4.3.5 Data: Time history plots of selected parameters listed in Table 1.

4.4 OBJECTIVE: Evaluate cockpit environment during gun firing missions throughout program.

4.4.1 Requirements Reference: Ref 1.4 and 1.7.

4.4.2 Test Conditions and Procedures: Conditions will be on a ride along basis and as specified during the gun firing missions. The pilot will conduct the first several firings on 100% oxygen and take air bottle samples before and following the firings. The air bottle samplings will be taken to determine if the cockpit is free of noxious or toxic fumes. During the remaining gun firings the pilot will place his oxygen regulator on normal oxygen.

4.4.3 Support Requirements: A safety chase, gas sample bottles installed in aircraft prior to flight (cabin contamination level - Seq No 55 or WQ55), and gas sample analysis.

4.4.4 Data: Pilot comments, results of gas sample analysis, and time history plots of selected parameters from Table 1.

4.5 OBJECTIVE: Evaluate ability of the ECS to maintain a proper cockpit pressurization schedule.

4.5.1 Requirements References: Ref 1.1, 1.2, 1.3, 1.4, 1.6, and 1.8.

4.5.2 Test Conditions: A military power climb from approximately 5,000 feet PA to 50,000 feet will be accomplished.

4.5.3 Test Procedures: A military power climb at about .88 IMN will be performed beginning at 5,000 feet PA. During the climb the pilot will mark the altitudes in 2,000 feet increments, i.e., 8K, 10K, 12K and so on. If possible, the pilot will also read out cabin altitude during the climb. Pilot will level off at 50,000 feet and after approximately 30 seconds perform a rapid descent.

4.5.4 Support Requirements: Barometric pressures and temperature information for altitudes up to 50K from the weather service.

4.5.5 Data: Pilot comments, data from weather service, time history and tabulated values of SC 40 and EC04.

4.6 OBJECTIVE: Evaluate the ability of the ECS to provide and maintain comfortable temperatures and humidity ranges throughout the flight envelope.

4.6.1 Requirements Reference: Ref 1.1 and 1.4.

4.6.2 Test Conditions: The conditions will be those on the ground and at all altitudes up to the operational ceiling and all airspeeds up to Vmax at various altitudes. These points will be on a ride along basis.

4.6.3 Test Procedures: Throughout the flight envelope, the pilot will sample temperature and humidity conditions by taking a record with the onboard instrumentation package. Records will be made using selected settings on the temperature control knob. System response to setting changes will also be determined. These tests will be conducted in both auto and manual temperature control modes, and emergency vent (Dump)/bleed air OFF conditions.

4.6.4 Support Requirements: F-15 No. 3, onboard instrumentation set on alternative program (program B) for recording temperatures.

4.6.5 Data: Time history plots of parameters listed in Table 2.

4.7 OBJECTIVE: Determine the cockpit depressurization, repressurization, and leakage rates.

4.7.1 Requirement Reference: Ref 1.1 and 1.8.

4.7.2 Test Conditions: Emergency cabin pressure dump and ventilation will be selected at the following conditions:

Pressure Alt (feet, PA)	Indicated Mach No.
3,500	0.33
5,000	0.41
5,000	1.11
10,000	0.37
10,000	1.15
35,000*	C.90
60,000**	2.00

*Cabin leakage test condition.
** Pilot will wear pressure suit.

4.7.3 Test Procedures: Emergency dump and ventilation will be selected at the stabilized test conditions listed in para 4.7.2. For the 60,000 feet point the pilot is required to wear a full pressure suit, which will be checked out during the climb at approximately 35,000 feet. Depressurization and pressurization rates will be calculated. At 35,000 feet and approximately 300 KIAS the pilot will switch bleed air source to OFF position. Cabin dump will not be selected. The pilot will maintain 35,000 feet until the cabin altitude equalizes with the aircraft altitude.

4.7.4 Support Requirements: Full pressure suit (only the 60K test point).

4.7.5 Data: Time history plots of selected parameters listed in Table 1, and pilot comments. Contractor data will be used for the 60,000 foot test point.

4.8 OBJECTIVE: Determine the capability of the ECS to provide adequate temperatures and flow rates to avionics equipment bays and to minimize temperature variances.

4.8.1 Reference Requirements: Ref 1.1, 1.2, 1.4, 1.9, and 1.15.

4.8.2 Test Conditions: Same as para 4.6.2.

4.8.3 Test Procedures: Similar to para 4.6.3; however, emphasis will be placed on the avionics air supply. All avionics equipment, except for ICS (Internal Countermeasures System) will be in operation. The ICS cooling airflow has been provided; however, it cannot be evaluated until actual ICS equipment has been installed in the aircraft. The radar shall be placed in Long Range Search (LRS) mode with Medium Range Missile (MRM) selected. The cabin and avionics temperature/flow controllers will be set on schedules as determined by the contractor (set prior to flight). The pilot will observe and note anytime the AV Hot Light illuminates.

4.8.4 Support Requirements: Same as 4.6.4 plus temperature decals in a range of 110 - 180 degrees F to be placed in avionics compartments.

4.8.5 Data: Pilot comments, time history plots of selected parameters listed in Table 1, and post flight readings from temperature decals in the avionics compartments.

4.9 OBJECTIVE: Evaluate the ability of the anti-fog subsystem to prevent formation of frost or fog in the mission essential transparent area of the windshield/canopy.

4.9.1 Requirements Reference: Ref 1.1, 1.2, and 1.4.

4.9.2 Test Conditions: The test will begin with a cold soaking of the aircraft for at least 30 minutes at 40,000 feet MSL at about 250 KIAS (.82 IMN). Then a rapid descent to 1,000 feet MSL (or AGL) will be performed.

4.9.3 Test Procedures: The aircraft will proceed out to the PMR at or above 40,000 feet at approximately 250 KIAS or as consistent with engine placards. A rapid descent at a -60 degree pitch angle with engines in idle and speed brake extended will be performed. The aircraft will remain subsonic and initiate pullout above 6,500 feet MSL and recover no lower than 1,000 feet MSL. The descent will be made with the temperature control knob at a selected setting. If during the descent frost or fog begins to form, the pilot will select a warmer position on the control knob that will eliminate the condition.

4.9.4 Support Requirements: Onboard instrumentation and safety chase.

4.9.5 Data: Selected time history plots of measurands from Table 1, pilot comments, and ambient conditions from Weather Service, i.e., temperature, humidity, barometric pressures in vicinity of tests.

4.10 OBJECTIVE: Evaluate the capability of the oxygen subsystem to provide sufficient oxygen throughout the aircraft's flight envelope in normal, 100%, and pressure demand.

4.10.1 Requirements Reference: Ref 1.1 and 1.8.

4.10.2 Test Conditions: Same as para 4.1.2 and 4.6.2.

4.10.3 Test Procedures: The oxygen subsystem will be evaluated on a ride along basis at all points of normal aircraft operations to include some cabin dump points which require pressure demand above 30,000 feet pressure altitude.

4.10.4 Support Requirements: None

4.10.5 Data: Pilot comments.

4.11 OBJECTIVE: Determine any trends towards early or excessive ECS component failures.

4.11.1 Requirement Reference: Ref 1.1, 1.4, 1.8, 1.11, 1.12, and 1.13.

4.11.2 Test Conditions: No specific test conditions required.

4.11.3 Test Procedures: The ECS will be monitored for proper operation on all flights.

4.11.4 Support Requirements: Access to MCAIR maintenance records and information from the F-15 data retrieval system.

4.11.5 Data: Pilot and maintenance comments, time history plots of selected parameters in Table 1 if a system failure occurs.

4.12 OBJECTIVE: Evaluate the ability of the ECS to provide adequate cooling airflow to the Internal Countermeasures System (ICS).

4.12.1 Requirement References: Ref 1.1.

4.12.2 Test Conditions: Conditions will be on a ride along basis and as specified during the Tactical Electronic Warfare System (TEWS) missions.

4.12.3 Test Procedures: Throughout the ground and flight envelope, the pilot will take records of the ICS temperatures and pressures. For ground operations the ICS will be in the standby mode and records will be taken under varying ambient conditions. During ICS operations records will also be taken at selected conditions with all avionics ON. In addition to the parameters listed in Table 3, temperature decals in the range from 110-180 degrees F will be placed on the ICS units.

4.12.4 Support Requirements: Same as 4.8.4 plus F-15 No. 10.

4.12.5 Data: Pilot comments, time history plots of parameters listed in Table 3, and post flight readings from temperature decals in ICS compartment.

APPENDIX C

ANALYSIS, EVALUATION AND PRESENTATION OF TEST RESULTS

[redacted] [redacted] [redacted]

TABLE OF CONTENTS

[redacted]

INTRODUCTION

The final report will give a brief description of the environmental control system, explaining the basic logic of its operation and its principal operating modes. The report will then discuss in turn each component of the system (bleed air system, cabin pressurization and so on). The general approach will be to:

a. describe the component and its function

b. present the evaluation criteria

c. describe the test results

d. state whether the evaluation criteria were met

When the criteria are not met enough detail must be provided to effectively define the shortfall in each case. Tabular summaries will be given where appropriate, time histories will also be given with attention drawn to the important parameters. Photographs should be used where appropriate. A general format is suggested below followed by a discussion of functions, evaluation criteria and pertinent parameters for each component. The writer should, however, be familiar with and conform to current report format rules.

FORMAT

Test Objectives:

State that the objective is to determine whether the component meets its specific requirements and also whether it is operationally acceptable. A brief summary of the specific requirements may be desirable.

Description of Test Item:

A short description should be given of the component being tested, supported by a schematic. Describe its various operating modes, including operation with partial failure and emergency operation as appropriate.

Test Methods and Conditions:

Describe these in general terms. Details of the tests are probably best combined with discussion of test results.

Test Results:

Present results in narrative form, including a short statement of overall results and trends supported by tabular and graphic data as appropriate.

Narrative.

Summarize overall results and conclusions with qualifying remarks as necessary. If the component is satisfactory, so state. Discuss deficiencies in sufficient detail to effectively define the problem. Service Reports (S.R.s) submitted during the test program should be referenced and discussed as appropriate. It may be desirable to include copies of all SRs as an Appendix.

Tabular Data.

Present tabular summaries of the tests conducted which should include:

1. Flight identification (date, flight number, aircraft, etc.)

2. Key parameter for the specific component and test

3. Comments as appropriate

Graphical Data.

Present time histories of dynamic tests as appropriate. Use photographs to illustrate problem areas and deficiencies.

BLEED AIR SYSTEM

The bleed air system consists of the ducting and components that pass high and low pressure bleed air from the engine parts or other compressed air sources to the various subsystems that use bleed air. These sources may include any/all engines, an Auxiliary Power Unit and ground support equipment.

Test Objectives:

The test objectives are:

1. to determine whether the bleed air system provides air at the flow rates, temperatures, pressures, moisture content and priority required by each subsystem or component using bleed air

2. to determine whether the bleed air system can provide the maximum required combined flow under the mose adverse conditions (e.g. descent at idle power)

3. to determine whether the bleed system meets other performance and design requirements, summarized in Tables A1A and A1B (page 91 and 92)

4. to evaluate the bleed air controls (shut off valves, cross over, etc.) provided to the crew

Key Parameters:

These are

1. bleed air system configuration

2. flight conditions (if airborne)

3. engine settings

4. pressure, temperature and mass flow of air delivered to each using subsystem/component

5. pressure, temperature and mass flow of air from end regime/APU

6. moisture content, where applicable

7. containination

8. ground and flight crew comments

PRESSURIZATION OF OCCUPIED COMPARTMENTS

The basic functions of the pressurization system is to provide a comfortably low pressure altitude in the occupied compartments of aircraft with operating altitudes greater than 20,000 ft. For cargo and personnel transports, navigation trainers and early warning aircraft the cabin altitude is controllable by the flight crew. For other types it is to be controlled automatically. Performance and design requirements are summarized in Tables A2A and A2B respectively (pages 93 and 95).

Test Objectives:

These are:

1. to evaluate compliance with the general requirements summarized in Tables A2A and A2B

2. to evaluate compliance with any additional, aircraft peculiar, requirements

3. to evaluate operational acceptability

Key Parameters:

1. bleed air system configuration

2. cabin pressure control configuration

3. flight conditions

4. engine settings

5. compartment pressures

6. rate of change of pressure altitude

7. pressurization air flows

8. for pressure release tests, time to depressurize

9. leak rate (see Appendix D)

EQUIPMENT PRESSURIZATION

The function of the equipment pressurization system is to provide, automatically, the pressure environment called for by the electronic and other equipment. Equipment pressurization requirements for the aircraft type under test are given in the aircraft end item specifications and in the specifications of individual items of equipment. Equipment using free convection air cooling will conform to general standards defined in MIL-E-5400T. Equipment using other cooling techniques will usually have its own requirements.

Test Objectives:

These are:

1. To evaluate compliance of the equipment pressurization system with requirements

2. To evaluate operational suitability

Key Parameters:

1. System configuration and operating mode

2. Flight conditions

3. Engine settings

4. Pressures in equipment compartments

PRESSURIZATION OF RESERVOIRS AND INFLATABLE SEALS AND SUPPLY OF PRESSURE SUITS

This as a miscellaneous group, put together for convenience in writing this Handbook. It is probably best to report results on these separately.

Inflatable seals are part of the ECS. In the case of reservoirs and suits, however, the function of the ECS is only

to supply sufficient air at the required pressure and temperature to, for example, the fuel tank pressurization system.

Test Objectives:

These are:

1. To evaluate compliance with requirements for reservoir pressurization over all flight conditions (e.g. fast descent at idle power)

2. To evaluate effectiveness of inflatable seals, including effectiveness at maximum differential pressure and minimum pressure source output

3. To evaluate compliance with requirements of the pressure, temperature, moisture and contamination levels of the air supplied to anti g suits or pressure suits

Key Parameters:

1. System configuration and operating mode

2. Flight conditions

3. Engine settings

4. Mass flows, pressures, temperatures, moisture and contamination of air supplied

5. Crew comments on suit operation

AIR CONDITIONING OF OCCUPIED COMPARTMENTS

The system which air conditions occupied compartments is usually quite complex and the requirements it is to meet are demanding. Testing of the system may take up a substantial proportion of the total ECS test effort. In general, testing will address two areas

1. Temperature distribution - uniformity of air temperatures, temperatures of flows and radiating panels.

2. Performance under stresing conditions - cool down after hot soak, heating after cold soak, temperatures during extended cruise of loiter.

Test Objectives:

These are to evaluate overall operational suitability and to determine whether the system complies with the performance and design requirements summarized in Tables A5A (page 100) and A5B (page 102). The performance requirements include the following:

1. Ventilation rates to be at least 20 cubic feet per minute (cfm) per man for all operating conditions and at least 1.8 times the maximum allowable production leakage rate for all pressurized operations. Air velocities near seated personnel not to exceed 300 feet per minute (fpm).

2. Radiating surfaces not to exceed 105 degrees F near seated personnel during pressurized flight, and 140 degrees F for all other locations and conditions.

3. Air supplied to the occupied compartments to be free of entrained moisture.

4. Air supplied to the occupied compartments to be free of excessive contamination.

5. The automatic temperature control to maintain the average compartment air temperature to within ±3 degrees F of selected settings. Temperature variations between any two points in a seating envelope should not deviate more than ±5 degrees F from the average cabin temperature. Temperature differences outside the envelope not allowed to vary more than ±10 degrees F average cabin temperature.

6. Floor temperatures to be maintained above 60 degrees F average, with no location less than 40 degrees F.

7. Average cabin temperatures to be maintained between 45 degrees F and 90 degrees F for unpressurized flight and between 70 degrees F and 90 degrees F during flights with an inoperative ACM.

8. The cooling equipment to have sufficient capacity to maintain average compartment temperature at 70 degrees F except that it may be 80 degrees F for transients lasting less than 30 minutes.

9. Heating equipment to be capable of maintaining an average compartment temperature of 80 degrees F.

10. The ECS is to be compatable with the service equipment called for in Technical Orders.

Key Parameters:

1. System configuration and operating mode

2. Flight conditions/ground conditions

3. Engine settings

4. Temperatures in seating envelopes

5. Average temperatures in occupied compartments

6. Temperatures flows and of radiating surfaces

7. Compartment inlet temperatures and flows

8. Air velocities at crew positions

9. Contamination and noise

10. Crew comments

EQUIPMENT CONDITIONING

Equipment requirements cover a wide range and some items such as radar transmitters, impose high loads on the cooling system. Equipment cooled by free convection air cooling is subject to a standardized set of requirements (MIL-E-5400) but other items of equipment have their own specifications for cooling. The requirements the equipment conditioning system is to meet should be found in the aircraft end item specifications and individual equipment specifications. The final report must include a description of the equipment conditioning system and its operating modes and an overview of the requirements it is to meet.

Test Objectives:

These are:

1. To evaluate compliance of the equipment conditioning system with specifications in both flight and ground operations

2. To evaluate operational suitability, including any adverse effect of any constraints imposed by equipment conditioning on e pment operation.

3. To evaluate compatability with support equipment called for in Technical Orders.

Key Parameters:

1. System configuration and operating mode

2. Flight conditions/ground conditions

3. Eng settings

4. Equipment heat loads

5. Weight flow, pressure, temperature, moisture level and contamination of air flow in and out of equipment compartments, heat exch rs etc.

6. Weight flow and temperatures in liquid cooling loops, in to and out of heat exchangers

7. Water and potential funqus problems

8. Crew comments

ANTI-ICING OF NON TRANSPARENT AREAS

If anti-icing is required on Air Force airplanes it is usually limited to areas such as ECS air scoops or radomes. Flight evaluation of such protection would use one of the AFFTC tanker water spray systems.

Test Objectives:

To evaluate the ability of the anti-ice system to maintain satisfactory operation of the specified components under the flight conditions defined in the aircraft requirements, for the meteorological conditions defined in Figure A1. (page 123)

Key Parameters:

1. Flight conditions

2. Ambient air temperature

3. Component performance parameters (including temperature of anti-icing and/fluid, surface temperatures and electrical power if applicable)

4. Position of test aircraft relative to tanker

5. Liquid water content of spray

6. Photo records of ice build up

7. Crew Comments

ANTI-ICING OF TRANSPARENT AREAS

Anti-icing protection is required for the windshield, bombardiers panel (if any) and other "mission essential" areas. Flight evaluations of this protection will usually use the AFFTC water spray tanker.

Test Objectives:

These are to evaluate the ability of the anti-ice system to protect mission essential areas for all conditions of flight for the meteorological conditions summarized in Figure A2, (page 124).

Key Parameters:

1. Flight conditions

2. Ambient air temperature

3. Component performance parameters (including temperatures of anti-icing air/fluid, surface temperatures and electrical power if applicable)

4. Position of test aircraft relative to tanker

5. Liquid water content of spray

6. Photo records of ice build up on transparent areas

7. Crew comments

DEFROSTING AND DEFOGGING OF TRANSPARENT AREAS

Defrosting and defogging capability as required for windshields, bombardiers panels and all other mission essential areas for all flight conditions and in taxiing. Areas to be protected include those needed for taxiing.

Test Objectives:

These are to evaluate the ability of the defrost/defog system to protect all mission essential transparent areas during taxiing and under all flight conditions.

Key Parameters:

1. Flight conditions and flight profiles (e.g. fast descent after cold soak)

2. Defog system operating configuration

3. Defog air temperature and mass flow (if hot air used)

4. Surface temperatures

5. Meteorological conditions and temperature and humidity in cockpit

6. Crew comments (including impact of system on crew comfort)

7. Photo record of frost/fog build up

REMOVAL OF RAIN AND SNOW FROM TRANSPARENT AREAS

Pilot and copilot windows are to be protected against heavy rain or snow, and sensor windows are to be protected for all

conditions for which sensor operation is required (Table A10, page). Windshield protection against "excessive rain" is to be sufficient to enable a safe landing. Heavy rain is 0.59 inches (1.5cm) per hour (1500 micrometer median droplet diameter) and excessive rain is (1.6 inches per hour, 2300 micrometer median droplet diameter). Flight tests will be made when suitable weather is available. Simulations will be conducted using one of the AFFTC spray tankers and possibly in the Climatic Laboratory.

Test Objectives:

These are to evaluate the protection of transparent areas against heavy rain, excessive rain and snow. Protection against heavy rain or snow is to be provided for:

1. Taxi, take-off, landing approach and landing

2. Flight at 1.6 times the stall speed at maximum weight with gear and flaps up (fixed wing aircraft)

3. Flight at maximum cruise speed (rotary wing aircraft)

4. In flight refuelling conditions, if refuelling is required below 20,000 feet

Protection against excessive rain is to be sufficient to enable a safe landing

Key Parameters:

1. Flight conditions

2. Rainfall rate

3. Jet temperature and mass flow (if air jets used)

4. Surface temperatures in impingement area

5. Crew comment on protection

6. If feasible, photographic records of the clearance

PROTECTION AGAINST DUST, SALT AND INSECTS

Protection is required for pilots and copilots windshields and for sensor windows on aircraft where mission requires low level flight over the oceans or along the coast (salt) or over land (dust and insects). All vertical take off and landing aircraft are to have protection for the pilot and copilots windshields (Table A11, page 119). Flight tests to evaluate the protection will be conducted when weather/sea conditions are suitable.

Test Objectives:

These are to evaluate the protection in relation to requirements.

Key Parameters:

1. Flight conditions
2. Weather conditions
3. Sea state (for salt protection)
4. Area successfully protected
5. Flight and maintenance crew comments

. OXYGEN SYSTEMS

These will be evaluated during normal flight missions and servicing. Requirements are summarized in Table A13.

Test Objectives:

These are:

1. To evaluate the oxygen system for proper functioning throughout the flight regime, in normal and emergency modes
2. To evaluate servicing and maintenance
3. To evaluate clarity and convenience of crew control

Key Parameters:

1. Functioning in normal operation
2. Functioning during depressurization
3. Crew comments on controls
4. Ease and safety of servicing

APPENDIX D

MEASUREMENT OF LEAK RATES

OF OCCUPIED COMPARTMENTS

[redacted]

The usual equation for the density of a "perfect" gas is:

$$\rho = p/(RT)$$

Where
ρ = density
p = pressure
T = absolute temperature
R = "gas constant"

Since the mass (M) of air in the compartment is equal to the product of the density and the compartment volume (V) we may write:

$$M = V\rho/(RT)$$

Accepting the usual engineering mix of units, as follows:

M = lbs mass
V = cubic feet
P = pounds force per square inch
T = degrees Rankine

This equation becomes:

$$M = 2.70\ VP/T$$
$$= 2.70\ V(P_a + \Delta P)/T \qquad \text{(D1)}$$

Where
P_a = ambient pressure

ΔP = cabin pressure differential

Differentiating this equation we have, since V, T and P_a are constants:

$$\frac{dM}{dt} = \frac{2.70V}{T}\frac{d(P_a + \Delta P)}{dt}$$

$$= \frac{2.70V}{T}\frac{d}{dt}(\Delta P) \qquad \text{(D2)}$$

Note that the same time units must be used on both sides of this equation.

To determine the initial leak rate, at nominal differential pressure, the simplest procedure is to plot the differential pressure against time on semi-log paper and determine the initial slope. If semi-log paper is not available one may plot $\log_{10}(\Delta P)$ against time and then determine the initial slope of this curve. To use this we note that:

$$\log_{10}(\Delta) = \log_{10}e \, \log_e(\Delta P)$$

and hence

$$\frac{d}{dt}\left[\log_{10}(\Delta P)\right] = (\log_{10}e)\frac{d}{dt}\left[\log_e(\Delta P)\right]$$
$$= (\log_{10}e)\frac{1}{\Delta P}\;\frac{d}{dt}(\Delta P)$$

That is:

$$\frac{d}{dt}(\Delta P) = \frac{\Delta P}{\log_{10}e} \quad \frac{d}{dt}\left[\log_{10}(\Delta P)\right]$$

Substituting in equation (D2) we now have:

$$\frac{dM}{dt} = \frac{2.70V}{T}\frac{(\Delta P)}{\log_{10}e} \frac{d}{dt}\left[\log_{10}(\Delta P)\right] \tag{D3}$$

Where ΔP and the slope are evaluated at time zero

Figure D1 shows data from AFFTC-TR-81-26 plotted in this manner, giving:

$$\frac{d}{dt}\left[\log_{10}(\Delta P)\right] = -0.017$$

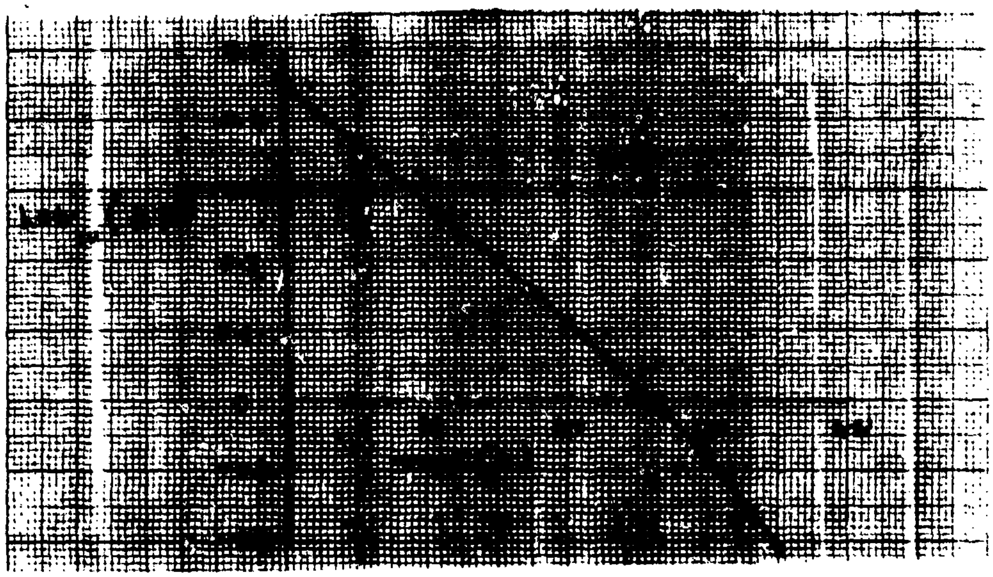
$$\Delta P = 2.84$$
$$V = 65$$
$$T = 518$$

and hence:

$$\frac{dM}{dt} = -\frac{2.70}{518} \times 65 \times \frac{286}{0.434} \times 0.017$$

$$= -0.0381$$

This corresponds to 2.28 lbs/min



Time (s)	Cabin Pressure (psia)	Cabin Diff Pressure	Log_{10} (Diff Pressure)
0	11.14	2.84	0.45
5	10.65	2.35	0.37
10	10.33	2.03	0.31
15	9.90	1.60	0.20
20	9.60	1.30	0.11
25	9.33	1.03	0.01
30	9.14	0.84	-0.08
35	8.92	0.62	-0.21

Air Temperature (T) = 518°R

Cabin Pressure (V) = 65 c. ft.

Figure D1 Determination of Cabin Leak Rate